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Great Barrier Reef Committee

VOL. IV. PART I.

With Seven Plates.

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VOL. IV., PART I.

No. 1.

NOTES ON THE GREEN TURTLE (Chelonia mydas).

By F. W. MOORHOUSE, M.Sc., late Marine Biologist of Queensland.

(Plates I.-III.)

1.—INTRODUCTION.

Turtles are found the world over; some are restricted to certain very limited areas only, while others are cosmopolitan and are found mainly in the tropical and subtropical waters of all the oceans. Along the Barrier Reef, from south to north, there are present in considerable numbers at least three species of turtles—the green turtle (*Chelonia mydas*), the loggerhead turtle (*Thalassochelys caretta*), and the tortoiseshell or hawkbill turtle (*Chelonia imbricata*).

As little is known of the life-history and habits of the green turtle (*Chelonia mydas*), and as these animals are being taken in large numbers from the many islands along the coast of Queensland, more particularly in the Torres Strait, where the natives make them an important article of their diet, observational and experimental work on the laying period and on the rate of growth of the young turtles was carried out from October to February, 1929-30, with a view, not only to the adding to our knowledge of these animals, but also to the recommending of restrictions on the taking and killing of the adult animals if such was considered necessary.

Heron Island, situated at or about the southern extremity of the Great Barrier Reef and 55 miles north-east of Gladstone, was chosen as the centre of these inquiries. The island is somewhat cigar-shaped and approximately 1 mile in circumference, surrounded by a moat of varying width and depth which never dries even at the lowest tide. The whole of the south sandy beach is protected by beach limestone, but the north shore is composed of white coral sand, there being no limestone deposits present.

The writer remained on the island from 31st October, 1929, until 16th February, 1930. Since turtles arrive mainly after nightfall and at any state of the tide, paradings of the island were carried out each night with but one exception, due to extraordinarily inclement weather. In the early part of the work parades were made from nightfall till midnight and again from 2 to 5 a.m., but as the season progressed and the actual counting of the eggs became unnecessary, owing to the fact that the hatchings would occur after our departure, paradings were at intervals, generally three times a night, viz.:—7.30 to 8.30; 10.30 to midnight; and again at 3.30 to 5 or thereabouts. During parades, only those turtles that came up on the island and laid their eggs were counted (excepting the marked animals which were counted each time they came up, whether they laid or not). This was done because a study of the habits of the turtle in general was one of the objects of the investigations.

Canning of turtle soup had been carried on at Heron Island for some years, work commencing early in November and finishing in February. During the 1928-29 season, so scarce did the turtles become towards the end of the season that periodic visits had to be made to the neighbouring islands in order to obtain sufficient animals to keep the factory in active operation. In view of the facts that the last season's animals were wiped out and that there was a considerable number present this season, one deduction is that turtles seen in any one season on any given island do not necessarily return the following year to lay, but that there is a period of rest between layings—that laying seasons are separated by some years. This is offered tentatively and can be proved or disproved only after some years of investigations.

2.—Marking of Adult Turtles.

In order to recognise the turtle under observation each was labelled. The labels were of copper sheeting about 1 inch square attached to the carapace by a wire passed through a hole bored in one or other of the pygal plates. The right bottom corner of each label was removed, the better to orientate the label during reading, and each label had a number punched on it. The original numbers were from 1 to 50, but as the 5 was difficult to distinguish in subsequent readings, labels 5, 15, 25, and 45 were discarded and the following—61, 62, 64, and $\underline{\cdot\cdot}$ substituted. The labels proved a very satisfactory method of marking, but five animals were not seen again after labelling. It is more than probable that the labels of these animals were torn off by the male during copulation.

Turtles arrived on the island on 31st October, though it is reported that some had visited the island during the two previous nights. The first animal was labelled on the 4th November, but the marking of the animals did not start in earnest till 13th November because the animals coming up in the early part of the season were taken by the proprietors of the factory (*a*) for canning purposes, or (*b*) for sale to the freezing works at Gladstone.

With a view to finding the percentage hatch of young per nest, the eggs were counted as they were laid, the nest was marked by a stake bearing the same number as the label, and finally the animal was labelled. The label was added in order, as stated earlier, to show the returnings, if any, of these animals. By 23rd November fifty animals had been labelled, all the nests had been marked, the eggs of most counted, and the number recorded.

Amongst the first marked were five animals that had been turned over and left on the beach by visiting fishermen. On each of the two nights following, one of these five animals came back to the island and on both occasions was turned. On the second turning over she was actually transported to the factory to be killed but was later liberated. A report was received that on 15th November, ten days after her labelling, this animal had been seen laying on North-West Island, some 16 miles from Heron Island. Her subsequent layings were carried out on Heron Island.

Turtles are powerful swimmers, though they cannot maintain a high speed for any length of time, but on land they are not at all at home. When turned over on their backs on shore, they are quite helpless. The turning is easily carried out by first gripping the carapace at the pygal region and then lifting at the moment the turtle has completed her forward pull with the fore flippers. While in the turned position they make numerous futile attempts to right themselves and the fore flippers are waved about and frequently beaten against the plastron with resounding slaps. Care must be taken, however, not to venture too near the swinging flippers, for nasty wounds have been inflicted by the horny toe arming each. It was our custom to turn the turtles before boring the hole to take the label, but it was found that this was unnecessary labour, for the turtle took no notice of the process if it were carried out as she filled in her nest after laying.

During the marking of the last few animals, the earlier marked had commenced to return for their second laying. Many of the animals had a total of seven layings, though the returnings in some cases were as numerous as twelve. In many returnings the animal walked about the beach, and after perhaps digging a nest or two, went back to the water to return on the following night at some other point on the beach to lay. Some of the animals in their meanderings covered 600 yards besides digging one or two nests.

3.—Breeding Season.

The breeding season in this southern area of the Barrier Reef commences in late October and extends at least into mid-February. During this time the females have been observed to lay seven different lots of eggs, and it is quite possible that since turtles were still returning on 16th February, when investigations ceased, that seven is by no means the maximum number of layings per season.

The males, distinguished from the females by their very long tails, have never been seen on the beach at any time of night or day, though they frequently come close in-shore.

Copulation appears to occur right through the season; pairs were seen floating on the surface of the smooth seas during October and November and again in January (Plate I., fig. 1). During copulation the couple float at the surface and frequently appear to go to sleep, for with care it is possible to row right up to the beasts.

The female lays her eggs in a hole which she digs generally above high-water mark. Layings do not occur at each return. In moving up the beach, the animal progresses by stages of six or seven steps, resting for longer or shorter periods between stages. In walking, the green turtle brings the fore flippers to the front and with a heave of the body and a pushing with the hind flippers moves her body forward a few inches on the way up the beach but as much as a foot on the way down, the tail leaving a characteristic stubbing in the centre of the track (Plate III.). The track left in the sand is quite different from that of the loggerhead turtle, which, walking like a four-footed beast, leaves an open set of prints.

As soon as the turtle reaches a suitable site, generally above high-water mark, she commences to remove the surface sand by flappings of her fore flippers while the hind ones pile up the sand behind her ready for the filling in of the nest after laying is completed (Plate II.). Her body is lowered to a level with the general surface, and finally most of the weight rests on the edges of the carapace. Then follows the digging of the egg pit, the hind flippers only being used. As the cupped flipper deposits the sand by the side of the animal the other flipper, which has been resting outstretched, is flicked forward to remove fallen sand and then carefully placed in the hole. As the hole is deepened the animal lifts herself up by her fore flippers so as to allow her hind flippers to dig deeper, the body pivoting on the carapace edges. After completion of the egg pit, which is a cylindrical hole undercut at the bottom, and which is 18 inches deep and 1 foot in diameter, the hind flippers are brought together to shield both tail and orifice and laying commences. The number of eggs at a laying is approximately 120, though as many as 195 and as few as 66 have been counted.

As soon as the laying is completed the nest is filled in, the hind flippers patting and kneading the sand into the nest. Then follows a flinging of sand over the body by the fore flippers, the hind ones piling it evenly as it falls. The animal, still throwing sand, moves forward and soon the original spot is obliterated. Then she returns to the water. From the time of the turtle's coming out of the water till her return two to two and a-half hours have elapsed, though some animals have taken but one hour, while others have taken as long as seven hours in the process.

Many animals have commenced to dig the egg pit and then left the spot. This is due not to any desire on the part of the animal to hide her true nest but because of (1) the meeting with a tree root or some other obstruction too large to be broken or removed; (2) the falling in of the sand under the animal's weight; (3) interruption due to (*a*) another turtle in search of a site blundering in on the one digging; (*b*) man—this applied more to those animals that had suffered the hurt of tagging; or (4) the animal's urinating in the prepared pit.

From the close of November onwards turtles came up in large numbers—as many as fifty-one animals arriving on the one night. Owing to this large number of animals coming to lay, there were few places on the island where no visit had been made, and many thousands of eggs were laid. Some points on the island appeared more favourable than others, though the turtles came as readily across the beach limestone which lines the whole of the south side of the island as they did across the sandy places. Owing to the large number of visits, later arriving animals frequently, when preparing their egg pit or when covering in their nest after laying, dug up old-established nests and scattered the eggs which in the morning were devoured by the sea-gulls. Not only were our nests for observation disturbed, but the marks also were removed and much of the earlier work vitiated. One nest of 81 eggs was destroyed some few days before the expected hatching and, though many of the young thus ejected were again covered none survived.

Considerable variations in the sizes of the carapaces of the laying animals were seen. The measurements were made along the carapace from nuchal shield to middle of the pygal shields for length, and across the carapace from edge to edge passing across the middle of the central neural shield for width. The largest animal was 48 by 42 inches and the smallest 35 by 35 inches. But of the fifty animals that were taken at random thirty-three were between 40 and 43 inches in carapace length, five were less than 40 inches in length, while the remaining twelve were greater than 43 inches. On several occasions, animals were met with that appeared smaller or larger than those mentioned above, but in all cases they were found by measurement to fall within the groups already given. Some small animals were seen swimming in the deep channel to the south of Heron Island's reef-edge, but it was not possible to capture one of them. A search for small turtles was made on the reef flat and in a deep lagoon to the east of the island, but without success.

4.—Enemies of Mature Animals.

The many enemies of the small turtle will be given later, but mature animals are not immune. Sharks appear to cause much damage, and animals have been seen with a large piece bitten out of the carapace and with flippers missing; probably the result of shark attacks. One female in particular had her flippers so badly mutilated that she could not clamber up the beach. She therefore made a simple nest and laid her eggs in it at the very water's edge.

But all cases of missing flippers are not due to attacks from other animals. A newly-hatched turtle was found dead and its right hind flipper was represented by a small knob; other young have been obtained direct from the nest with the tail missing and with hind flipper, of one side or the other, deformed.

5.—Eggs.

The eggs of the green turtle are spherical in shape and $1\frac{3}{4}$ inches in diameter. They are slightly larger than those of the loggerhead turtle, which are also spherical but $1\frac{1}{2}$ inches in diameter. The number at a laying varies from 66 to 195, the average being approximately 120.

When laid, each egg is not completely filled and therefore is slightly dinted. This depression generally disappears after several days of incubation, the filling-out being caused by the absorption of water from the damp sand surrounding the eggs, for eggs placed in sand that had been washed, thoroughly dried, and left under cover, were found to have shrivelled due to loss of moisture.

Similar shrivelling was seen in eggs left open to the sun and air. On opening these eggs the yolk appeared to be intact but all the "white" had disappeared. The white of the egg, of a particularly jelly-like consistency when new-laid, is composed mainly of water and contains very little albumin. When heated it is found not to coagulate. According to reports, retorting new-laid eggs under 15 lb. pressure of steam also fails to bring about coagulation, but if the eggs be exposed to the sun for one day and then boiled coagulation will occur.

The eggshell is parchment-like and is applied in layers, the outermost being impregnated with lime. In some eggs this outer layer flaked off but the contents did not appear to suffer any ill-effects, for development appeared to be normal.

Stages in the development of the embryo, commencing with the first day of incubation and carrying on up to the thirty-eighth day, were taken, but further critical examination of these embryos has not yet been carried out.

Development of the eggs in different nests was not uniform, but in any one nest there was fairly close uniformity. After one day of incubation the eggs, which are translucent when laid, showed the presence of a white patch on the upper pole. There the albumin had become closely apposed to the shell and in the centre of the area the developing embryo would be seen as a clear patch when the egg was viewed in reflected light. After many attempts to obtain this stage success was at last forthcoming. By carefully cutting on the inner edge of the white patch the whole area was easily removed, and by soaking this for a short time in a salt solution (sea water) the embryo soon floated off. On about the seventh day of incubation the egg was turgid and the jelly-like white a liquid. From this time onwards all embryos were easily obtained.

The following stages and conditions of the embryo have been taken —the times are only approximate:—

2 days old—Body of five somites.

10 days old—The heart closed and beating regularly, the flipper buds definite, and the eye well advanced.

13 days old—The allantois a small sac-like outgrowth.

30 days old—Ribs and plates plainly marked off, eye enormously enlarged.

38 days old—Carapace taking on colour; head, lower jaw, and flippers move at will.

Experiments on the planting out of eggs were made at the early part of the season. The eggs were obtained from two sources—(1) From the oviducts of animals killed for soup making; (2) from nests made by the females.

From the first sampling, *i.e.*, the eggs from the killed females, five nests were made; four of these were made on 8th November, the other being made on 1st January. The number of eggs per nest, the young that hatched, and the percentage per nest are as follows:—

Nest.	Number of Eggs.	Young hatched.	Percentage.
1	122	12	10
2	88	9	10
3	107	..	..
4	98	25	24
5	95	Not hatched at tim	e of leaving islan d.

With reference to the low percentages, it should be stated that from No. 1 nest at various intervals during the development period, eight eggs were taken in order to note progress. Each of these was developing normally, so that it is fair to assume that under ordinary circumstances the young would have been hatched from them, thus giving a percentage of sixteen from this nest. No. 2 nest was disturbed by a loggerhead turtle and when found many eggs had been thrown out. As this state of affairs occurs so frequently the percentage must stand. No. 3 nest was composed of eggs taken from the floor of the factory where they were floating around in the water that is freely used during the killing and cleaning of the animals to be used in the soup making. Some, too, had not been extracted from the portion of the oviduct containing them, so that during the development they were open to the attacks from the innumerable nematodes that are found in the decomposing mass. The necessity for the complete removal of all offal from the eggs that are planted out is therefore illustrated. No interruptions to No. 4 nest occurred, so that, though the percentage hatch is low, the young make a welcome addition to those naturally occurring. The important fact that eggs taken from killed turtles and planted out will develop has been demonstrated.

Since the policy of turning turtles before they have laid is still unfortunately adhered to by all persons met with, factory proprietors as well as ordinary fishermen, the proprietors of factories should see that all mature eggs are removed from the offal of the killed animals and planted out. The amount of time expended in carrying out this work is extremely small and once the planting is done no further attention is required. For the sake of the turtle industry, this should be done.

The second method of planting out eggs, from nests made by the turtles, was carried out because it was generally thought that, since there are so many eggs to each nest and yet so small a percentage hatches out, the earliest hatched animals devour the other less fortunates in the nest. This is certainly not correct, for there is yolk in excess of that required for the developing turtle, and this is drawn into the body cavity just prior to the animal's breaking from the egg-shell. In fact, some almost fully developed young have been seen with the yolk sac still external, and in two instances these animals were taken a day or so after and it was found that the sac had been drawn in through the umbilicus. The yolk sustains the liberated turtle for several days, and young kept in aquaria have been one week without attempting to eat. As soon as they are hungry they commence to dive, being especially attracted by pink objects such as portions of Tubipora or Voluta shells. Young loggerhead turtles, however, are ready for food in two days, and they swim at the surface with their mouths open to the full extent and showing white against their otherwise totally brown drabness.

Before the fact that there is excess yolk was discovered, two nests had been divided up. The eggs were planted out in smaller nests, each containing 12, while 22 and 36 were left in the original nests. In not one instance did the planted-out eggs come to full development, though all opened showed that there had been arrested growth of the embryo, and subsequent death. From the original nests, 17 from the former and 19 from the latter were the total hatchings. The failure is due in all probability to the fact that development had commenced in the eggs

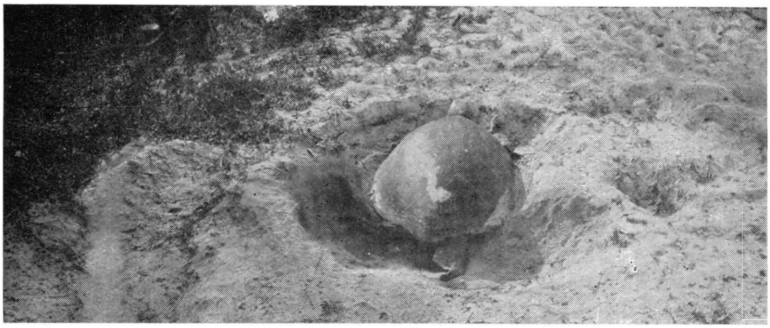

Fig. 3.

After the body-hole is completed, the turtle commences to dig the egg-pit. The right flipper has just deposited its sand, while the left one is flicked to throw off the fallen sand before it is placed in the hole.

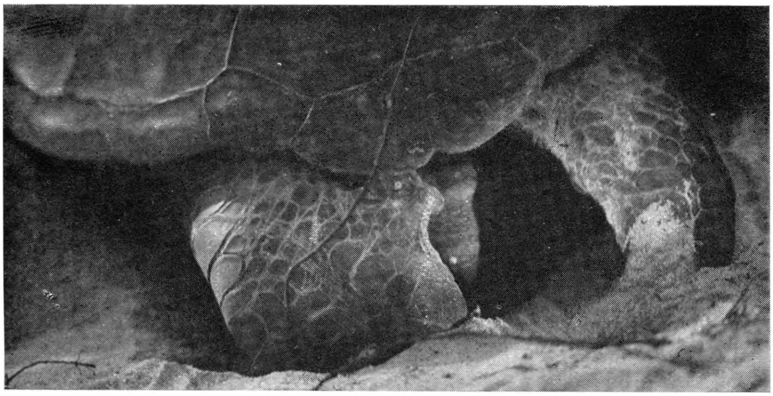

Fig. 4.

As soon as the egg-pit is completed, the flippers are brought together to cover the tail and orifice, and laying commences. The right flipper was drawn back in order to show the tail.

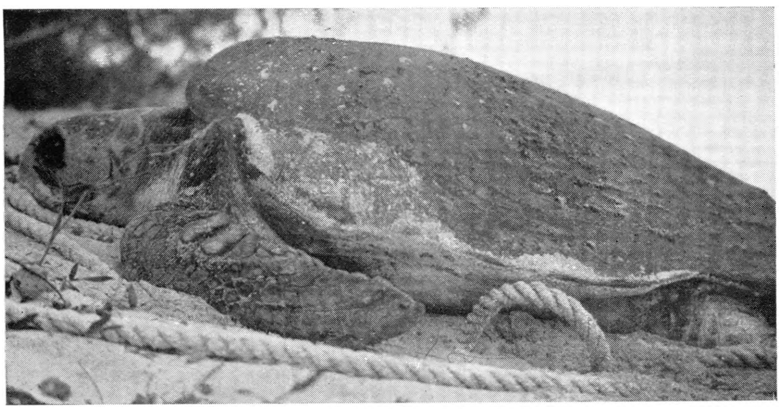

Fig. 5.—A Loggerhead Turtle.

Note its thick neck and its large head. The turtles are of little commercial use at present, though there are possibilities of utilising them in the production of turtle oil.

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before they were removed to the smaller nests, and that injury was caused to the embryo during the transplanting.

6.—Percentage Hatch.

The small percentage of hatchings, occurring in the eggs taken from killed females and planted out, has already been shown, so that for those eggs laid in the orthodox manner much better results would be expected to obtain. In the case of those eggs in nests that remain undisturbed this is so, but many instances will be seen later where 0 per cent. resulted.

Nests are usually made above high-water mark, but this mark during the month of November was considerably more than a foot below that for the month of January, so that many nests then out of reach of the tide were covered by the later higher tides, while others were laid bare or washed out by the resulting wave action. No young resulted from these nests, so the six nests under the heading "Destroyed by Sea's Encroachings" in the list to follow produced 0 per cent.

Of the fifty nests marked during the first laying, the following is a summary of results:—

Definitely known Hatchings.	Destroyed—		Lost Trace of or not Known.
	By other Turtles.	By Sea's Encroachings.	
11	10	6	23
(Percentage page 10)	(Percentage ?)	(Percentage 0)	(Percentage ?)

Unfortunately the "Lost Trace of" column contains 46 per cent. of the nests of the marked animals. Of these twenty-three instances, five nests belonged to animals marked early in the season. These turtles had been turned by visiting fishermen and unfortunately left on the beach, so that it is almost safe to assume that they had not laid before being turned. The returning of some of these animals on following nights is recorded, but as they were turned once or even twice again it is probable that all left and laid elsewhere. Actually one animal was seen by a fisherman, who reported that it had laid on North-west Island, 16 miles from Heron Island.

Of the other eighteen nests, the majority had their marking stakes thrown out by turtles, and so were lost trace of. It would appear that they should be included under "Destroyed by Turtles," but that column is reserved for nests in which the eggs were definitely known to have been destroyed. From many of these nests some young were probably produced.

The information dealing with the eleven nests of the first laying which were not disturbed and from which hatchings resulted is here tabulated:—

Animal's Number.	Eggs.	Young produced.	Percentage Hatch.	Date of Laying.	Date of Hatching.	Incubation Period.
						Wks. Dys.
1 ..	85	50	59	4th Nov.	10th Jan.	9 4
10 ..	139	67	50	13th Nov.	17th Jan.	9 2
13 ..	68*p*	89	?	14th Nov.	18th Jan.	9 2
16 ..	106*p*	77	*ca*72	16th Nov.	27th Jan.	10 2
19 ..	152	77	50	15th Nov.	25th Jan.	10 1
20 ..	119	63	53	16th Nov.	26th Jan.	10 1
24 ..	119	66	55	16th Nov.	27th Jan.	10 2
25 ..	113	58	51	17th Nov.	25th Jan.	9 6
31 ..	105*p*	68	*ca*65	18th Nov.	26th Jan.	9 6
33 ..	90	37	41	19th Nov.	26th Jan.	9 5
48 ..	141	123	86	23rd Nov.	30th Jan.	9 5
* ..	150	83	55	17th Nov.	24th Jan.	9 5

* In the above list is a Loggerhead Turtle which was observed in order to compare with the Green Turtles. It will be seen that the number of eggs produced, the percentage hatch, and the incubation period follow closely those seen for the Green Turtle, and that since two other marked nests were destroyed the losses in the nests of these animals are as great as are those in the Green Turtle.

NOTE.—*p* alongside the number of eggs (68*p*) signifies that the total was in excess of that given ; the animal had commenced laying when found.

7.—YOUNG TURTLES.

The first young turtles seen on Heron Island were found on 6th January just below the surface of sand covering the nest. As these eggs were laid on the 2nd November, this gives the incubation period of these animals as nine weeks two days. But it was not till 9th January that the animals broke through the sand on their own account after nine weeks five days of incubation. In popular writings on turtles it has frequently been stated that the incubation period was from six to eight weeks, according to the fancy of the writer, but the present investigations have proved this a fallacy, the time being from nine and a-half weeks to ten and a-half weeks.

Many hatchings were noted, and in all cases the time was in excess of nine weeks after the laying. Most of the nests from which young emerged in just over nine weeks were in open tracts of sand, unprotected from the summer sun for long periods each day. In those nests on the north side of the island where Casuarinas, Tournefortias, Pandanus, and other forms of vegetation grow close to the water's edge and give much shade, the period of incubation of the eggs has been considerably lengthened, and as much as ten weeks and two days have elapsed between the laying and the hatching. It therefore follows that the development of the eggs in different nests is not uniform, but from the hatchings it is seen that in any given nest there is fairly close uniformity.

The young from any one nest, however, do not all emerge on the same day or night. It was frequently noticed that part only of the young emerged on a particular night, to be followed on the next night or two after by the remaining portion. In some cases the first escaping was but a very small proportion, while in others the major portion escaped at the first break through.

It has been shown that a low temperature due to shade, caused either by vegetation or by clouds, retards progress. Rain also causes a delay in hatchings, for the sand is so hardened by the moisture that the young find it impossible to break through until the sand dries again. One instance out of several such will suffice. After a reasonable interval the young from a marked nest had failed to emerge. Their arrival time coincided with a week of heavy rain, so the nest was opened from one side and thirty animals were seen huddled together in a perfectly formed underground cave, caused by the settling of the egg-shells and of the sand torn down by the baby turtles in their endeavours to escape. When the cave was breached these young emerged, and twenty-five from beneath the floor of the cave also broke through.

As soon as the young turtles emerge from the nest they head for the sea, but should there be a bright light in their vicinity they are attracted to it and walk round and round it, resting for short intervals only. Even after the young have reached the sea they have come to the shore again at the approach of a bright light; on three different occasions animals attracted by the light from petrol lamps have left the water.

Young turtles walk like most four-footed beasts, leaving a characteristic and open track in the sand. The young green turtles thus differ from the adults, which advance by a series of heaves during which both fore flippers are brought forward to pull while the hind ones push.

When they reach the water the young swim straight out to sea, the fore flippers working up and down together, reminiscent of the wing action of a bird in flight. The hind flippers are trailed behind, coming into use only when the turtle rises to the surface to breathe. During this time both the fore and the hind flippers are moved one after the other and the animals appear to tread water.

Turtles are air breathers and therefore it was thought possible that they would survive in fresh water. Young ones were kept in an aquarium of fresh water and, though many appeared healthy, the majority preferred to remain out on the bank. There were many deaths amongst these animals, whereas of those in salt water pools only one death occurred. The fresh water experiment proved a failure.

It may be mentioned here incidentally that eighty-three young loggerhead turtles were kept in a fresh water pool for five weeks and all at the end of that period were in perfect health.

In the salt water pools the young often remain motionless on the surface for long periods with the limbs stretched to their full extent. Others remain in a corner with the head resting on a ledge out of water and the limbs tucked about them in various positions.

For up to seven days after hatching the animals make no attempt to eat and it was found, on dissecting several that had been inadvertently killed or drowned, that there was still a large percentage of the yolk within them.

When the young were seen biting at objects in the water—they were especially attracted by the pink coral *Tubipora musica*—it was judged that they were hungry, so food was given to them. Since the adults are herbivorous, it was thought the young were also. Seaweeds were, therefore, placed in the pools and in all cases, though the weed was bitten off, it was rejected shortly after. Most of the species of algæ occurring on the reef flat were placed in the pools in the hopes that the right kind would be amongst them, but all were rejected, as also were bread, biscuit, and oatmeal. It so happened that several small fish had been placed in a turtle pool in order to act as indicators to give warning when the water was foul. After a very heavy series of rain squalls the pools were filled with fresh water, and it was noticed that the fish, now showing signs of distress, were being pursued by the turtles. One was caught, torn to pieces, and eaten. After that, the food given to the young turtles was fish, clam, and meat. Young green turtles are therefore carnivorous. The following is its method of obtaining its food:—With mouth open the turtle approaches the food and obtaining a firm grip with its chisel-like jaws it forces the food away with its fore flippers, and tugs at it with all its might. The particles thus torn off are chewed under water, the excess water taken in with the food being forced out through the nostrils. The captive turtle in the observation pools readily took food from the hand and as readily dived for small pieces dropped into the water.

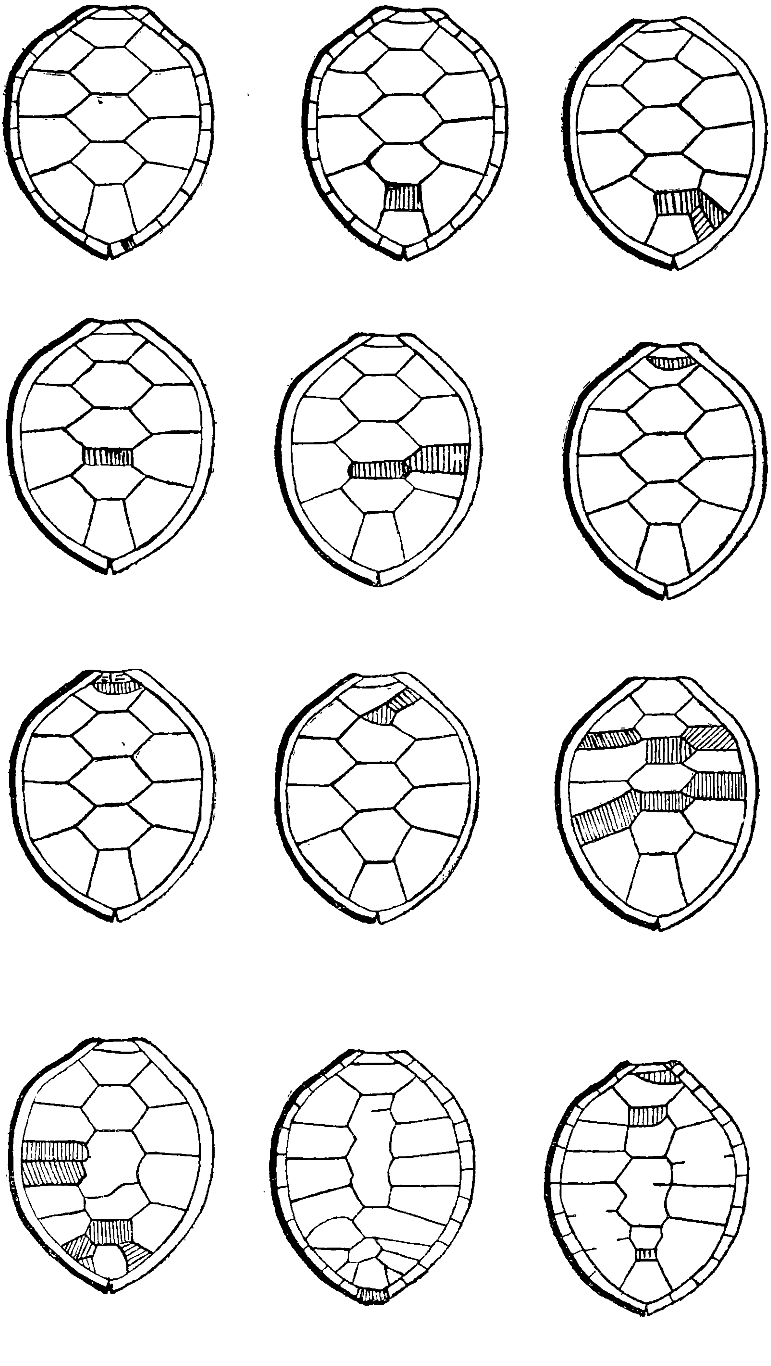
According to Gadow's account of turtles in the *Cambridge Natural History,* one would not expect to find much variation in the shields of the carapace of the green turtle. It came as a great surprise to find in the first collection of young green turtles that out of a number totalling forty-six there were fourteen non-uniform carapaces or 33 per cent. not normal, whereas from eighty-three young loggerheads there were but twenty-three or 27 per cent. not normal.

The normal number of shields on the carapace of a green turtle is thirteen large, made up by five neurals and four pairs of costals, and twenty-five small, composed of twenty-four marginals and one nuchal. Of the fourteen abnormalities mentioned in the last paragraph there were twelve different departures and two duplicates. These are diagrammatically depicted in Text figure 1, the additional plate or plates being shaded. Two (Nos. 11 and 12) were so irregular as to defy interpretation.

Many hundreds of young turtles were collected. From one nest ninety-five young were obtained and not one animal possessed a set of

TEXT FIGURE 1.

ABNORMAL CARAPACES IN *CHELONIA MYDAS*.



irregular shields, yet from two other nests, of forty-three and twenty-five young, respectively, there were seven and five abnormal sets. The high percentage of abnormalities seen in the first animals collected is then not a coincidence. It is probable that, since there are mature females with shields that differ from the normal, their progeny will be liable to variations also; but the young arrived too late for a verification of this statement to be made.

Adult male green turtles differ from the females in that they possess a very long tail, approximately a foot, or more, in length. It was thought that a similar sexual dimorphism would be seen in the young, but no distinguishing features have been noticed. All young appear alike—omitting the exceptional, *i.e.*, the deformed ones, and the very small ones which, liberated by me from amongst the lowest tiers of eggs, would, under ordinary circumstances, have failed to free themselves.

Besides the abnormalities in the shell just described, several deformed young have been met with. One of these was dead when found. Instead of the normal right hind flipper, that appendage was represented by a rounded knob. A condition similar to this has been seen in the adult of both the loggerhead and the green turtles, but it had been thought that the flipper in these cases had been bitten off by some enemy such as a shark. It is probable that some of these instances are due to arrested growth, though others, without doubt, are caused by attacks from various animals.

A second case was the one whose shell is shown in No. 11 above. This animal had no tail and the hind flippers and that portion of the carapace and body posterior to the hind legs were non-pigmented. This animal lived for a long time in the aquarium and appeared to thrive. Under normal conditions such would certainly fall a ready prey to fish, judging by the number of successful attacks upon it by the other young turtles in the same aquarium. A third turtle had the right hind flipper turned inwards and malformed. This animal was the last to arrive from one of the planted nests. It, too, lived when placed in the aquarium.

Despite these cases there is a remarkable uniformity in size of the carapaces, and, though some small animals occur, the majority have the following dimensions (on hatching):—Nose to tail, 3 inches; carapace (length), $1\frac{7}{8}$ inches; carapace (width), $1\frac{1}{2}$ inches; plastron (width), $1\frac{3}{8}$ inches; head (length), $\frac{7}{8}$ inch; thickness of body, $\frac{3}{4}$ inch.

The colour of the carapace when dry is slate grey, but on being wetted this changes to a dark blue. The edges of the carapace and of the limbs are faintly blue at time of liberation, but this darkens with age, leaving after a month but a very thin strip of light colour. The plastron is uniformly white.

The umbilicus is at first very definite, having frequently the appearance of a rounded knob; but gradually this protruding mass is withdrawn, the shields of the plastron in this region come together, and in about three weeks all trace of the umbilicus has disappeared.

8.—Enemies of Young Turtles.

Since much damage is done to eggs and potential young by turtles that arrive for a later laying, turtles themselves must be included in the list of enemies.

The baby turtles generally break forth from their nest at nightfall. Should they come to the surface before this part of the day, they usually remain beneath the sand. Some have broken through in daylight, however, but in most cases they have buried themselves again. Others have commenced the hazardous journey to the water, but invariably have been taken by gulls and herons.

At night the birds have disappeared, so these enemies are not then to be contended with. But the nocturnal large shore crab, Ocypoda, feeds on the beach and many young turtles fall victims to him. These crabs are present in large numbers, but it is only the bigger members of the species that attack the turtles. As it stands over its prey, the crab grips it firmly with one claw while with the other it removes the shields of the carapace, generally commencing with those in the tail region of the shell.

On Heron Island there is another enemy which is perhaps peculiar to this island. This is the common house cat, which has so multiplied that it now forms a real menace to the young turtles, for each cat frequently takes seven or eight turtles for a meal and eats the head only.

In the water, sharks and large fish await young turtles, so that the percentage loss is extraordinarily high.

9.—Marking of Young Turtles.

The marking of young turtles appeared a problem because their backs are but 2 inches in length, whereas those of the adults are 3 feet or more. Owing to the number of adults that have been seen with part of flippers missing, the attaching of labels to flippers did not seem a satisfactory method of marking. Since carapaces are too small to afford suitable places for fixing labels, it was decided to experiment by snipping off the extensions of the pygal plates. When it was ascertained that, though slight bleeding occurred at first, the snipped animals appeared to have suffered no ill-effects, 1,300 animals were marked in the same way and liberated at night. They swam towards deep water and up to the present not one has been seen again.

10.—Growth in Young Turtles.

A very close uniformity in the carapace measurements of the young as they emerge from the nest is seen in the case of both the loggerhead and the green turtles. Occasionally in a batch of young there are some definitely small animals, but they form a very slight percentage of the hatch. They appear to be those from the lowest tiers of eggs and generally are badly formed due to pressure. This is only a temporary malformation and they fill out later. Many of these, however, do not live more than a few days.

The measurements of six representative young were taken at intervals in order to show the increase by growth. Though the list shows that this is not great it is certainly appreciable, and is quite noticeable when newly-hatched turtles are placed in the pools with the older ones, an action that is not recommended, for the new ones continually struggle to escape and thus disturb the now-contented older captives.

NORMAL ANIMALS.

Where Measured.	No. 1.		No. 2.		No. 3.	
	25th Jan.	10th Feb.	25th Jan.	10th Feb.	25th Jan.	10th Feb.
	In.	In.	In.	In.	In.	In.
Nose to tail (variable) ..	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{8}$	$3\frac{1}{4}$
Carapace—						
Length	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$2\frac{3}{8}$	2	$2\frac{1}{8}$
Width	$1\frac{5}{8}p$	2	$1\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}p$
Plastron—Width	$1\frac{1}{2}$	$1\frac{5}{8}p$	$1\frac{1}{2}-$	$1\frac{5}{8}-$	$1\frac{3}{8}$	$1\frac{1}{2}$
Head—Length	$0\frac{7}{8}p$	$1-$	$0\frac{7}{8}$	$0\frac{7}{8}$	$0\frac{7}{8}$	$0\frac{7}{8}$
Thickness of body	$0\frac{7}{8}$	$0\frac{7}{8}p$	$0\frac{7}{8}$	$0\frac{7}{8}p$	$0\frac{7}{8}$	$0\frac{7}{8}$

ABNORMAL ANIMALS.

Where Measured.	No. 1.		No. 2.		No. 3.	
	25th Jan.	10th Feb.	25th Jan.	10th Feb.	25th Jan.	10th Feb.
	In.	In.	In.	In.	In.	In.
Nose to tail (variable) ..	3	$3\frac{1}{2}-$	3	$3\frac{1}{8}-$	$2\frac{7}{8}$	3
Carapace—						
Length	$1\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}p$
Width	$1\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}-$
Plastron—Width	$1\frac{1}{4}p$	$1\frac{7}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$
Head—Length	$0\frac{7}{8}$	$0\frac{7}{8}$	$0\frac{7}{8}-$	$0\frac{7}{8}$	$0\frac{7}{8}-$	$0\frac{7}{8}$
Thickness of body	$0\frac{3}{4}$	$0\frac{7}{8}p$	$0\frac{3}{4}p$	$0\frac{7}{8}-$	$0\frac{5}{8}$	$0\frac{3}{4}$

The increase in growth of young turtles is shown on the shields of the carapace. The horny matter making up these shields is secreted by cells of the epidermis immediately beneath them, so that the first formed natal piece remains uppermost, the new layers being added from below. Each new addition is a little larger than the one deposited before it, so that, in effect, the shields are very much flattened truncated pyramids owing to the thinness of the added plates. But the new portion is added in different manners in the various shields. That of each neural shield is so placed that the anterior portion projects more than does the posterior part, so that with increasing growth the original shield is left towards the rear of the shield.

With costal shields the additions are greater to front and outer sides, *i.e.*, to the side that is nearest to the marginal shields, while in the marginals the increase is to the front and to the inner sides more than to the rear.

Since the additions to the anterior portions of the shields are twice as great as those to the posterior portions, the natal shield will come to occupy a position that is approximately a third of the length of the shield from the posterior end. It would be expected from this that, once the yearly growth of a shield is known, then the age of the mature turtle could be found from its shields either by noting the position of the original shield or by sectioning the shield at or about the position of the natal portion. But the older portions of shields are continually peeling off, so that it is not by this method that the age of mature turtles can be found.

It was thought that it would be possible to estimate the age of a mature turtle by taking shield measurement. At birth, for instance, the fourth neural shield is $\frac{3}{8}$ inch long, whereas a 44-inch animal has these shields $8\frac{1}{4}$ inches long. Since the $\frac{3}{8}$-inch shield increased to seven-sixteenths of an inch in a month, then the $8\frac{1}{4}$-inch shield, having increased by 126 sixteenths, will have taken ten and a-half years to have reached that size, assuming a uniform monthly rate of increase. But if the third costal shield on the right side of the same animal be used, then, since a $\frac{1}{2}$-inch shield, which in one month grew to $\frac{5}{8}$ inch, has, in a 44-inch animal, increased to $14\frac{3}{4}$ inches, the age would be only nine and a-half years. If this method is reliable and if growth is uniform, then 44-inch turtles are approximately ten years of age.

Young turtles seen on Murray Island in January measured 8 inches along the carapace from nuchal to pygal shields. Three had been captured early the previous year and had been kept in a small aquarium made from clam shells, *Tridacna gigas*. Their food was mainly a small herring, boiled trochus, and clam. One-year-old turtles are 8 inches long.

11.—Preservation of Young Turtles.

The many dangers that have to be faced by the young turtles immediately they are free from the nest have been given, so methods of preservation have been tried.

Those nests that were marked and remained intact were cooped shortly before the young were expected to arrive. The coop was a small-meshed wire-netting cage of 2-foot sides with covered-in top. This was sunk 6 inches in the sand surrounding the nest. No young could escape; therefore the cages were inspected each evening till the young appeared, and for some days after their first appearance, in order to obtain the later arrivals. The young were removed and placed in pools made above high-water mark, or in floating cages of wire-netting, surrounding a wooden frame, which were anchored out in the water of the moat.

The pools were all straight-sided in order to keep the young turtles within bounds, and were enclosed by a wire-netting fence leaving a small path at the sides. The tops were covered in in order to keep out herons and gulls. It was a mistake, however, to impound the turtles in straight-sided pools, as they enjoy a walk and by their continued attempts to crawl up the straight sides they wore away the little horny toes of the flippers. After this had been noticed, ramps were added to the four corners of the pools up which the young scrambled on their way out. When they had had sufficient time out of the water they dropped back of their own accord. The pools for enclosing young turtles should be so constructed that their long axes are parallel to the beach and the side nearest to the beach should slope gradually down, giving a scoop-like depression. The turtles, when they come out of the water, should be supplied with shade, because the hot sun tends to desiccate them and the shields fall off or blindness follows, resulting in the death of the animal. The food of young turtles is fish, though, after they have been some time on this diet, they appear to relish a little seaweed. Any of the seaweeds found growing on the reef-flat were eaten in very small quantities. The food was suspended by cords at distances sufficient to allow room for several animals to eat at each point. Small fish, such as "hardyheads" (*Hepsetia pinguis*), were greedily eaten, but cooked fish was just as readily dived for.

Several attempts to find the destination of the young turtles were made. The turtles, followed by boat, were seen to go as far as the reef edge and there they disappeared. Whether they reached the open sea is doubtful, for, by wading behind others that were liberated at low water, it was found that large fish—"trout," morwong, and sweetlip—darting out from beneath coral ledges near the reef edge snapped them up in a moment. Not one of twelve thus followed escaped. Whether the same state of affairs obtains at night, which is the normal time of escape, could not, unfortunately, be discovered.

The necessity of forming large compounds in which to hold baby turtles until such time as they can fend for themselves is patent. These should be constructed in protected bays where small fish are abundant so that the supplying of food and the changing of water will be done by natural means. Any such compounds must be sufficiently high-walled to reach above high-water mark and must be covered with netting in order to prevent the ingress of birds. In such a place as Heron Island no such protected bay exists, so that large shallow basins would have to be constructed on the plan of that given on an earlier page.

Small floating cages were not a success, for in rough weather when the tide rose over the reef-flat the wave action tossed the young about and eventually drowned them.

12.—Deductions and Suggested Restrictions.

After the closing of the factory on Heron Island, which, during November, 1929, produced a hundred or so gallon cans of concentrated turtle soup, a tally of all the turtles that came up to lay was kept. Between 1st December and 16th February there were seen 1,755 turtles, and, as mentioned earlier, these were all females.

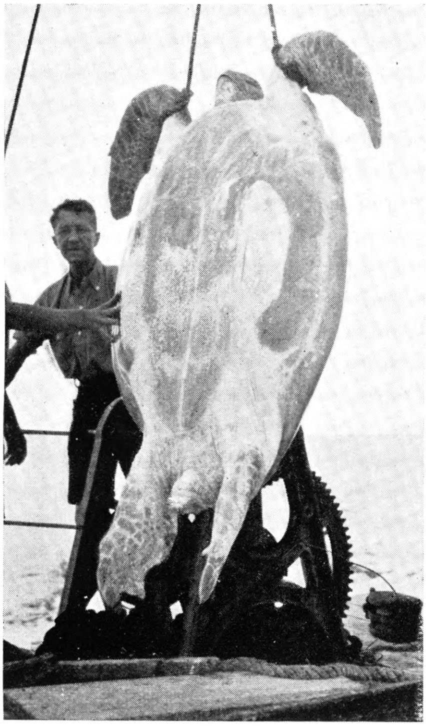


FIG. 6.
A $2\frac{1}{2}$-cwt. turtle being lifted up on to the truck to be taken into the factory.

FIG. 7.—THE TRACK OF A GREEN TURTLE.
This is a down track, as is so clearly shown by the direction of the impressions of the fore-flippers and of the tail stubbings. [*Photo., F. Ratcliffe.*

Face page 18.]

No males were ever included in the figures given in this paper, for no males were ever seen out of the water, and no males were ever killed at the factory.

Some of the labelled animals made as many as twelve returnings, but on only seven of these occasions were layings successfully carried out. Many of the animals that were not tagged but possessed such distinguishing features as a badly bitten-away carapace, one or other of the flippers missing, or an undivided horny shield covering the carapace, enabling them to be recognised again, were also seen on many occasions. The interval between layings is approximately fourteen days.

Though some animals were inevitably missed from the count by coming up and returning between our parades, the following definite results are here presented for the first time:—

(*a*) A very limited number of animals visit any one island during the breeding season.

(*b*) The same animals return again and again, seven being the maximum returnings recorded.

With this information now available these deductions can be drawn:—

1. The idea now prevalent that there are thousands of turtles visiting any one island during the breeding season is quite erroneous and must be replaced by *a limited number of turtles make many visits to any one island during the breeding season.*

2. Had the factory on Heron Island operated right through the 1929-30 season, there would have been seen towards the middle of the season that dearth of animals that has marked previous years when continued canning operations were carried out, mention of which was made in the Introduction of this paper.

3. Since the 1928-29 season's limited number of animals that visited Heron Island was completely wiped out, and yet some hundreds of animals were seen there the following season, then we are confronted with the following probabilities:—

(*a*) Turtles do not lay every season.

(*b*) Turtles that laid on an island in one season go to some other island the following season.

(*c*) Sufficient young mature each season to take the place of those adults killed during the immediate past season.

(*d*) There is a combination of (*b*) and (*c*)—*i.e.*, some turtles that laid elsewhere during the previous season, together with some lately-matured young, go to any one island for the next season; or

(*e*) Turtles that laid some seasons ago, together with some lately-matured animals, visit an island during the season.

Of the five points in No. 3, all that can be said at present is that (*c*) is the only point that can be definitely ruled out, for the turtles that came up to lay during the season varied, as shown in an earlier portion of this paper, from 35 to 48 inches in length of carapace, so that all those laying were not newly matured; in fact, only a small percentage of the laying females found on Heron Island was of such a size as 35 inches. It is a tentative hypothesis that 35 inches is the size of newly-matured animals—*i.e.*, in so far as Heron Island observations allow, green turtles first mature when they have reached a length of 35-inch carapace measurement.

At present in Queensland there is no restriction on the taking of turtles and there is further no regulation forbidding fishermen from taking animals before they have laid the eggs that they have come to the island to deposit. Though the short-sightedness of killing the turtles before they have laid is admitted, even by the hunters themselves, this unwise practice is still followed. If it is continued with, especially early in the breeding season, it must in the very near future deplete our stock of turtles to such an extent as to wipe out this branch of our fishing industry; therefore, a regulation should be framed in order to prevent the extermination of the turtle.

Any regulation regarding the taking of turtles should be such that a breach of it will become patent without the added expense of policing the waters to enforce it. In so far as turtles are concerned the matter appears simple. At Heron Island, turtles are taken on the beach as they come to lay, and since the laying season commences at or about the close of October in these waters, no turtles are seen upon the beach before that date. It is not till the middle of November that all the animals have been to the island to lay the first batch of eggs, so that by preventing the taking of turtles till the close of November all will have had the opportunity to have laid once, while many will have laid their second set. (N.B.—At the commencement of the season turtles were scarce, five or six being the normal number seen each night. The numbers gradually increased till early in January, when as many as fifty-one were seen on the beach in one night, after which the numbers began to decrease again rapidly till towards the close of the season only six or seven were seen each night.)

But the coast of Queensland is some thousands of miles in length, so that what applies in Southern Queensland does not necessarily apply in the north. The writer saw turtle eggs that had been laid in May in the Torres Strait islands, so that either the season is much more protracted in North Queensland or occurs in different months. If, then, regulations are to be framed they must at present state clearly that they apply to that part of the coast of Queensland south from Cairns at least (or latitude 17 degrees South) until such time as the length of the season in North Queensland is definitely known.

The regulation recommended should, therefore, be similar in form to that suggested hereunder:—

> "No person, south of latitude 17 degrees South, shall take, or offer for sale, and no person shall purchase, kill, or attempt to export, between the dates of 30th September and 30th November of each year, any turtle of the kind known as the Green Turtle (*Chelonia mydas*). Penalty £10 for each animal found in possession."

This close season is absolutely essential, for it is the only definite means of ensuring the laying of some of the eggs normally produced by the turtle. But if the fishermen and factory authorities could be compelled to plant the eggs from the killed animals, since it has been demonstrated that such action is advisable and profitable, then the yearly production of young turtles can be appreciably increased. It does not appear wise at the present juncture, owing to insufficient knowledge, to frame regulations to limit the *number* of turtles that shall be taken each season, or the *size* of animals permitted to be taken.

To illustrate how overfishing is viewed by other countries, a summary of ordinances and regulations introduced by them in order to ensure the natural restocking of their waters with turtle is here appended. Most of these countries carry a large native population.

WEST INDIES.

Barbados (1904).—No person shall take turtles or turtle-eggs from the shores of the island. No person shall set any net or seine within 100 yards of the beach.

St. Lucia (1911).—No person shall take, kill, sell, or buy and no person shall set a net with the object of catching turtles during the months from May to August, both included. Fines range up to £20 for any breach.

Turks and Caicos (1907).—There shall be a close season for turtles from May to September, both included. Neither eggs nor turtles shall be taken during these months. Fine, £20.

Grenada (1911).—There shall be a close season for turtles from April to September, both included. Neither eggs nor turtles found on land shall be taken. Fine, £5.

Jamaica (1914).—There shall be a close season for turtles (months not stated, but probably as for other West Indian islands). Turtles' eggs shall not be taken. Fine, £5.

Trinidad and Tobago.—Though there is a close season, the months are not given. There is further a restriction in size that it is permissible to take, but measurements are not given. Fine, £10.

EAST INDIES.

Federated Malay States (1915) sets aside areas from which no eggs may be taken. Fine, 100 dollars.

North Borneo (1917) allows eggs and turtles to be collected on condition that a license is held by the person collecting, but this does not apply to the natives, who have a special area allotted to them.

Philippines.—There appear to be no restrictions here.

OTHER ISLANDS.

Fiji (1923).—Turtles and their eggs are subject to the same restrictions as the fish; but the fish restrictions are not available.

Seychelles (up to the year 1919).—Turtles here had to be over 30 inches long and *were not allowed to be taken during the breeding season.* Eggs were not allowed to be taken, there being a fine of

500 rupees or 6 months' imprisonment for a breach. In 1919, however, the above Act was repealed and in its place was substituted the following:—*No turtles shall be taken.*

In conclusion, it must be admitted that much has still to be learnt. There has yet to be discovered the percentage of males and of females arising from each nest, and the percentage of these that actually reaches maturity. Further, a knowledge of where the young spend their lives is required and definite information on growth-rate has yet to be found.

13.—SUMMARY.

1. Of the fifty labelled turtles under observation, many were found to return to the island on numerous occasions and seven was the maximum recorded number of layings per animal. These layings occurred at approximately fortnightly intervals.

2. Copulation is carried out right through the laying season, which in the southern area of the Barrier Reef commences in late October. Animals (including some of the marked ones) were still laying when the writer vacated Heron Island on 17th February.

3. It is tentatively offered that females first mature when they have reached a carapace length of 35 inches.

4. The eggs produced at a laying vary from 50 to 195. The incubation period is from nine and a-half to ten and a-half weeks and the percentage hatch of nests under observation varied from 0 per cent. to 86 per cent. Eggs taken from the ovaries of killed turtles and planted out showed as high as 24 per cent. hatch.

5. Young turtles are greedily eaten by gulls, herons, terns, crabs, large fish, sharks, and cats. No sexual dimorphism was apparent in the young forms.

6. Young turtles were marked by snipping off the extensions of the pygal shields. They can be kept in aquaria of fresh water and are carnivorous in their early youth. Growth is noticeable by the additions to the anterior edges of the shields.

7. It has been shown that a very limited number of animals visit any one island during the breeding season and that these animals return again and again to lay.

8. The Government has been recommended to enforce the following regulation:—

> "No person, south of latitude 17 degrees South, shall take, or offer for sale, and no person shall purchase, kill, or attempt to export, between the dates of 30th September and 30th November of each year, any turtle of the kind known as Green Turtle (*Chelonia mydas*)."

This close season is considered absolutely essential, for it is the only definite means of ensuring the laying of some of the eggs normally produced by the turtle.

9. A summary of ordinances and regulations introduced by many countries in order to ensure the natural restocking of their waters with turtles is given.

No. 2.

THE COMMERCIAL TROCHUS (Trochus niloticus).

By F. W. MOORHOUSE, M.Sc., late Marine Biologist of Queensland.

Trochus niloticus, called "troca" by the natives of North Queensland and the Torres Strait, is one of three valuable products from our reefs, the other two being pearl-shell and bêche-de-mer. In Queensland it first came into prominence in 1912, when small consignments were despatched to Austria and Japan for use in the manufacture of cheap buttons. Shirt buttons which have on their under side red, brown, or greenish markings are made from *Trochus* shell.

Each year the production increased till the commencement of the Great War. The collecting of it was then given a fillip when diving for pearl-shell was prohibited, the attention of lugger and cutter owners being turned to this commodity. Japan then became the market, a position she still retains.

From statements made by those who participated in the collecting of *Trochus* in the early days, one gathers that enormous quantities were present on the various reefs and cays. Soldiers, returning to their island homes when the war was over, when hearing of the rise to prominence of *Trochus* conjured up visions of great wealth to be derived from the sale of the *Trochus* they knew had been left by them on their reefs; but their visions were never realised—the hunters had collected from their reefs those tons of shell that had been present years before.

A glance at the figures, taken from the Reports of the Department of Harbours and Marine and given as Appendix 1 to this paper, will suffice to show how rapid was the rise in production of *Trochus.* In the table of figures the production of pearl-shell is added to show how, in general, the falling-off in the production of the one article was accompanied by an increase in that of the other. For instance, as stated earlier, the war put a stop to pearl-shell diving, so that for 1916 there was no production of that shell, yet of *Trochus* there were produced 1,048 tons, a quantity only once exceeded since. The small quantity shown in the pearl-shell column for the year 1915 was left over from earlier activities.

But war-time precautions gradually eased and pearl-shell was allowed to be taken again. Within a short period the selling price of that shell rose to £200 per ton, so that much attention was devoted to it. There was still an incentive to search for *Trochus,* for each year its value increased; nevertheless its production declined. The drop in production of *Trochus* brought about a demand for the shell, and, therefore, the price continued to rise until 1920, when it reached the record price of £90 per ton.

During the next four years both pearl-shell and *Trochus* fell in price, and then there occurred a marked increase in price and production of both. In the case of *Trochus* these continued to rise until the year 1927, which gave the record production of 1,080 tons. It was at this time that a virgin portion of the Barrier Reef was exploited. Up to 1927 the *Trochus* hunters had not come further south than Mackay, but that year it was discovered that the Swain Reefs, in the vicinity of Rockhampton, were good bearing reefs, though their position was a very exposed one. These reefs mark the southern limit of the *Trochus* in Queensland.

Since the reefs were being regularly searched and as the southern limit of the habitat of *Trochus* had been reached, it became necessary for the crews to take small shell in order to maintain the yearly output of the vessels. This small shell—"chicken shell" it is called in the trade—did not bring such high prices and did not weigh one-fifth as much per shell as 3-inch shell, so that relatively a greater number of shells had to be gathered. Though many felt that it was unwise to take these small shells they still persisted in collecting them, simply because, if left, someone else would take them. Despite the yearly increase in price of *Trochus*—it rose to £80 per ton in 1929—there was a falling-off in its production. One reason might have been the better price that was offering for pearl-shell, but it is also possible that over-fishing, brought about by the indiscriminate taking of shell, was an important factor.

From 1927 there has been a gradual falling-off in the production of *Trochus* until 1931, when a slight increase was noticed. This last increase is due to the fact that, as the supply of pearl-shell was greater than the demand, numerous boats were taken from pearl-shelling and placed in the *Trochus* industry. Since there has been a further restriction in the output of pearl-shell, there will doubtless be a further addition to the *Trochus* fleet of 1932, so that the production for 1932 should show an increase over that for 1931, unless the 1932 regulations limiting the size of *Trochus* that may be fished have a slightly steadying effect.

Mention has been made of the transferring of vessels from the pearl-shell industry to that of *Trochus* gathering. The boats employed in both industries are deep draft sailing vessels with either one mast (cutter) or two masts (lugger). They are constructed in the yards at Thursday Island and cost approximately £1,000 and £1,500 respectively. The necessary equipment of a *Trochus* vessel is a "copper" for the boiling prior to the removing of the animal from the shell, together with three or four dinghies to be used by the diving boys for the collecting, so it will be seen that the conversion of a pearl-shell boat into a *Trochus* boat is readily and cheaply carried out. Finally, the license for a boat under the Pearl-shell and Bêche-de-mer Act holds good for the gathering of any of the three products, pearl-shell, *Trochus*, or bêche-de-mer.

The crews of these vessels vary from nine to as many as twenty persons, depending on the type of vessel and the capabilities of the men. The captains of the vessels belonging to the many large companies of Thursday Island choose their crews from the natives of the mainland, New Guinea, and the various islands of the Torres Strait. The general policy is to sign on a crew made up of some members from each of the three groups for reasons that will be apparent to the reader.

The Queensland Government has introduced a policy by which it is hoped to assist the natives of the Torres Strait and North Queensland to a self-supporting state. Each island has its own cutters or luggers (for instance, Murray Island has three cutters) manned by the natives of the island and captained by one of the tribe chosen by the crew under the direction of the Protector of Aboriginals at Thursday Island. These cutters generally carry a crew of ten; luggers have a slightly larger crew. One lugger, belonging to Badu and carrying a crew of twenty, has earned from *Trochus* collecting some £3,000 per year consistently over a number of years, but the records of the majority of the boats under this scheme are not so satisfactory.

The wage of the mainland boy is £2 10s. per month, but that of the native from the islands and from New Guinea—much better divers and workers than the mainlander, so it is said—is £3 10s. per month, making a yearly earning power of these boys of from £30 to £40 each. All have to be fed and clothed by the owner of the vessel. The earnings of the crews of the native luggers and cutters are far below this figure, and in some cases considerably less than £10 has been the yearly payment of each member of some of the boats; though, in fairness to the system, it must be said that they have contributed largely towards their own "Island Fund" from which old-age and sick pensions are drawn. For some years these vessels, known collectively as the Aboriginal Industries, have produced almost half of the *Trochus* exported from Queensland.

The marketing of *Trochus* shell is carried out at Thursday Island and by tender. The shell, spread out on the floor of the sale room, is viewed by the buyers who later submit their price per ton. The buyers are mainly alien or the Thursday Island representatives of alien firms, though one British firm, Bowden Pearling Company, which possesses its own fleet, is also a regular tenderer for the Aboriginal Industries' production.

The price of *Trochus* shell fluctuates considerably. Within recent history it fell to as low as £35 per ton, but at the close of 1931 it was up to £80, though the average price for that year was only £65 7s. per ton. At £80 per ton a kerosene tin full of *Trochus* shell would be worth approximately £1.

During 1928 to 1929 the writer, when attached to the Great Barrier Reef Scientific Expedition, carried out experiments on the growth rate and the age of maturity of *Trochus*. The results of this work are published elsewhere, but a brief account of the work is desirable.

By taking living *Trochus* of various sizes and specially marking the shell and the reef where the shell was liberated, it was found that, though there is slight wandering of *Trochus* along the reef the animals stay for considerable periods at or about the rock or boulder near which they were liberated or first seen. To mark the shell, a file mark was made on the whorl directly above the mouth of the shell. Each animal was numbered, the number being made in lead pencil on the nacre well within the mouth of the shell. Two years after my departure from the Island, during which time the reef was regularly visited by hunters, two of the shells were again found very close to the place from which they were liberated. They were first recognised by the external file-mark and, on carefully breaking through the shell (after the animal had been extracted) the lead pencil number was found to be quite distinct and legible. One of these shells is now in the Queensland Museum.

From my earlier work I had deduced that the growth was at the rate of 1 inch per year. From the animals that had been found after two and a-half years of free life on the reef this deduction was shown to be correct. The results are indicated hereunder:—

Shell.	Date Liberated.	Size.	Date Found.	Size.	Increase.	
					Total.	Yearly.
		cm.		cm.	cm.	In.
No. 20 ..	30th Sept., 1928	5·0	26th Mar., 1931	9·8	4·8	$0\frac{4}{5}$
No. 33 ..	30th Sept., 1928	4·7	26th Mar., 1931	10·7	6·0	1

The method of reproduction found in *Trochus* is similar to that of the edible oyster, *i.e.*, the products are freely scattered into the sea and there fertilisation takes place. Of some hundreds of animals that were found freely emitting their eggs (sperms are much more difficult to detect) the smallest was 4·4 cm. in greatest basal diameter—*i.e.*, from mouth of shell across columella to opposite side. But this animal was found on the reef-flat where conditions are not favourable for rapid growth, so that it is really a case of retarded growth. Retarded growth is characterised by two features—(*a*) An extremely thick shell which is correspondingly heavier than a shell of the same diameter taken from an area of normal growth, as, for instance, from the outer surf-beaten zone of the reef; and (*b*) a curved base, for all shell found on the outer edge of the reef are flat-based. The smallest animal from the outer zone that was found reproducing measured 5·5 cm., so that

Trochus are considered first mature when they measure 5 to 6 cm. or 2 to 2½ inches in greatest basal diameter. At this size the animal is two years of age.

On closely watching females that were reproducing, it was observed that the spawning period is a much protracted one. The eggs are laid a few at a time, usually as the animal retracts its protruding body. Several females first found laying in late March were still emitting eggs in late June, and on breaking the apex of one of these shells the ovary of the animal within was seen to contain enormous numbers of eggs that washed free quite readily.

The breeding season is therefore of some five months' duration. During this period the animals will have grown considerably, so that by the close of the breeding season they will have become 2½ to 3 inches in diameter.

The indiscriminate gathering of small shell is to be deprecated; therefore to insure the preservation of the industry a size restriction has been imposed. Much discussion as to the most suitable minimum size was heard, and finally 2½ inches was decided on. The writer feels that the minimum should be 3 inches.

By imposing a 3-inch restriction, in conjunction with a close season of seven months (from October to April, inclusive), New Caledonia has brought its *Trochus* industry to stability. The writer considers these restrictions very severe and burdensome. They are, in the light of present knowledge, somewhat excessive and tend to defeat their object.

The following information, received through the courtesy of His Excellency the Governor of New Caledonia and translated by the Consul-General for France in Sydney, shows the effects of the restrictions. First, there is a close season extending from 30th September to 30th April, during which no shell may be collected. Penalty for a breach of this regulation admits of—(*a*) Confiscation of the boat, (*b*) confiscation of the catch, (*c*) confiscation of the equipment, (*d*) suppression of the license. Secondly, there are prohibited sizes. *Trochus* with minimum diameter of 8 cm. (slightly greater than 3 inches) must not be taken, and any shell greater than 11 cm. must not be collected. Penalty, minimum fine of £1, maximum fine £8, together with those detailed under the first regulation. (This regulation gave rise to violent protests on the part of fishermen, traders, and factory owners, but the decree is still in force.)

In Appendix II. to this paper are set out the tonnage and value of the *Trochus* produced by New Caledonia from 1907 (the time it was first collected) to 1930. Each R in the table shows the year when a restriction was placed on the industry, so that the effects of the regulations on the production for the year following are the easier seen. In each case the effect of the restriction has been felt more or less severely during the year following its imposition, but, on the second year, conditions have become almost normal again.

In 1911 the restrictions, 8 cm. in greatest diameter and a close season of four months (January to April, inclusive), were imposed, yet in 1913 (two years after its imposition) there was the record production of 1,004 tons.

In 1916 the restrictions became more severe, for, instead of 8 cm. in greatest diameter, the order now read 8 cm. in minimum diameter, which means 9 cm. in greatest diameter, while the close season was increased by another two months, leaving an open season of but six months. The drastic nature of this Act was reflected in the production for the year 1917, for it fell to less than 200 tons, the lowest quantity ever recorded though fishing had been going on for over ten years. But it is pleasant to see that, two years after, the production had reached well up to normal with 749 tons.

For the small production for 1920 no explanation has been offered, so that in all probability domestic troubles were the cause.

In the year 1925 additional regulations were imposed, for the close season was then increased to seven months (October to April, inclusive) and a maximum basal diameter of 11 cm. added. Now no shell under 3 inches nor greater than 4½ inches in diameter may be collected from the reefs. No doubt, by the imposition of this latest size restriction New Caledonia is attempting to establish a permanent stock of breeders, but owing to the very short period (five months) that the men may work, and to the very large number of men engaged in the industry (1,500 men on an average), there is little likelihood that a great number of *Trochus* will escape. But despite these latest regulations there was seen a gradual increase in tonnage produced, commencing during the second year of their enforcement and continuing till 1929.

I am informed that during 1930 the button factories were out of commission, and, therefore, large stocks of shell remained unsold. This explains the small quantity recorded for 1930 in the table.

In the light of the above information it is safe to assume that little or no effect of the imposition of the 2½ inch in greatest basal diameter restriction will be felt by those engaged in the *Trochus* industry in Queensland, or that, if it is felt, it will be extremely slight and in our 1933 production a vastly increased tonnage will result.

APPENDIX I.

TONNAGE AND VALUE OF TROCHUS AND PEARL-SHELL PRODUCED BY QUEENSLAND.

	Trochus.				Pearl-shell.				
Year.	Weight.		Value.	Average Price per ton.	Weight.		Value.	Average Price per ton.
	Tons	Cwt.	£	£	Tons	Cwt.	£	£
1912 ..	35	14	637	17·8	450	11	92,363	205
1913 ..	41	5	735	17·8	451	12	109,745	243
*1914 ..	16	3	322	19·8	151	16	32,913	217
1915 ..	80	15	1,471	18·2	72	5	13,913	192·5
1916 ..	1,048	2	23,499	22·4	..		..	..
1917 ..	933	2	25,610	28·5	64	6	10,021	156
1918 ..	611	1	24,116	39·5	264	0	42,100	159·5
1919 ..	597	14	35,594	59·5	306	0	55,080	180
1920 ..	567	17	51,020	89·9	386	0	77,236	200
1921 ..	294	10	21,942	74·5	332	9	53,482	157
1922 ..	265	0	12,678	47·9	428	0	61,668	144
1923 ..	444	13	18,450	41·5	942	15	128,952	157
1924 ..	459	1	19,984	43·5	872	8	120,770	138·4
1925 ..	729	10	46,984	64·4	1,244	16	200,306	161
1926 ..	1,006	0	80,181	79·7	1,147	17	144,252	135·7
1927 ..	1,080	0	76,320	70·6	922	0	121,444	131·7
1928 ..	801	10	61,363	76·5	1,201	10	167,471	139·4
1929 ..	749	9	60,219	80·3	1,084	15	161,502	148·8
1930 ..	505	15	38,725	76·6	1,429	6	213,458	149·4
1931 ..	603	4	39,604	65·7	798	16	113,399	142

* Financial year changed from December to June.

APPENDIX II.

TONNAGE AND VALUE OF TROCHUS PRODUCED BY NEW CALEDONIA.

Year.	Weight.	Value.	Year.	Weight.	Value.
	Tons.	£		Tons.	£
1907 ..	927	7,213	1919 ..	549	12,661
1908 ..	821	6,380	1920 ..	184	6,938
1909 ..	588	4,435	1921 ..	929	20,654
1910 ..	906	10,870	1922 ..	714	12,108
1911R ..	531	9,410	1923 ..	382	10,823
1912 ..	730	20,130	1924 ..	490	16,654
1913 ..	1,004	32,710	1925R ..	363	19,139
1914 ..	577	19,120	1926 ..	362	26,952
1915 ..	466	30,040	1927 ..	357	17,081
1916R ..	790	25,910	1928 ..	358	19,340
1917 ..	187	5,177	1929 ..	386	21,921
1918 ..	749	29,320	*1930 ..	180	8,979

* Some important stocks remained unsold in 1930. They have not been included in the statistics on this account.

R Signifies year when regulation was imposed.

No. 3.

COMMERCIAL SPONGES FROM THE BARRIER REEF.

By F. W. Moorhouse, M.Sc., late Marine Biologist to the Government of Queensland.

(Plates IV.-V.)

At the present time the various types of sponges obtainable from the commercial houses of Queensland are all imported from overseas. The majority are from Greece and Italy and are the products of the Levant and the Mediterranean Sea, though some are imported from the United States of America.

At our doors there are present, and waiting to be utilised, sponges of fair commercial qualities. These sponges are eminently suitable for use in printing, painting, and decorative work, for car-washing, and for nursery use. It is admitted that, so far, no really first-class toilet sponge of the turkey-cup variety or quality has been located. There may lie hidden in the deeper waters many species (one has been located) that would prove suitable for the toilet trade, but dredgings are necessary in order to carry out a complete survey. Areas on the chart marked M (mud), however, may be eliminated from further examination, for it was shown by the dredgings carried out by the Great Barrier Reef Expedition that such areas are devoid of sponge life—in fact, of life in general.

On the reefs and cays of the Barrier Reef and on some of the islands within the lagoon channel, numerous species of sponges are to be found. There are three, at least, that are of sufficient importance and abundance to warrant their being classed as potential commercial products. They are all members of the Hippospongia.

One of the sponges, the commonest, is a shallow-water inhabitant and is found in the moats of the reef-flats of Low Isles, Three Isles, and the Hope Islands, as well as at Murray Islands in the Torres Strait. From these places samples have been collected and it is probable that it occurs on most of the islands from Townsville to the New Guinea coast. It is usually of a well-formed dome-shape and black in colour (Plate IV., fig. 1). When first cleaned, either by trampling on it or by allowing it to remain in sea water for two or three days and then washing and squeezing it in sea water, it has a yellow-brown colour, though dark chocolate stains at the base of attachment tend to detract from its appearance. The stain can easily be removed by bleaching with oxalic acid solution.

The second species lives on the outer surf-beaten zone of the reefs. It is strongly lobed and somewhat coarser textured than the first-mentioned. Usually, innumerable sand grains are caught up amongst its fibres, but being derived from calcareous material they are easily removed by immersion in an acid solution. This sponge has been

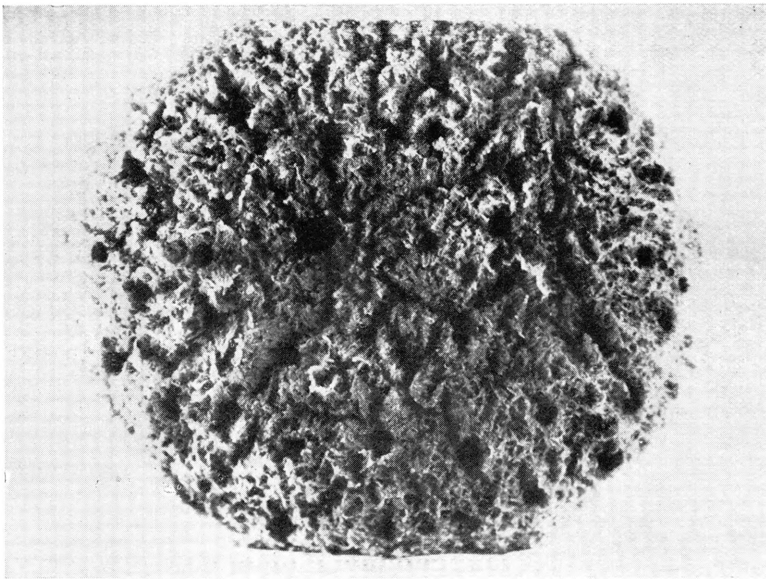


FIG. 1.—THE SHOALWATER SPONGE, 8 INCHES IN DIAMETER, SHOWING THE FINE TEXTURE AND PERFECT SHAPE.

[*Photo., C. Illidge.*

FIG. 2.—THE DEEP-WATER SPONGE. ITS CLOSE TEXTURE IS WELL SEEN. LENGTH, 4 INCHES.

Face page 31.]

[*Photo., C. Illidge.*

collected from Pixie, Michaelmas, Escape, and Ruby Reefs, and from Low Isles. Like the former it is black in colour when alive and cleans readily when treated soon after its collection from the reef.

The third species, obtained when dredging in 12 fathoms in the neighbourhood of the Turtle Group, north from Cooktown, is of a brown colour when brought to the surface, but on being cleaned it is found to possess a beautiful clean white appearance. Its most striking features are its remarkable tenacity and its delightfully smooth texture. This is the only species obtained up to the present that approaches general toilet sponge requirements, though its shape—elongate and almost cylindrical (Plate IV., fig. 2)—is its drawback.

Sponge-growing by fragmentation of bigger sponges is the method adopted by many sponge-producing countries of the old and the new worlds, and since our supply of sponges would probably soon be depleted by merely collecting those present, experiments were carried out with a view to finding the rate of growth and the farming possibilities of the first of the sponges enumerated above.

The first fragments were placed out in October, 1928. So successful were their growths that a series of experiments were commenced at the close of January. Three methods of planting out were adopted. These were the line, the house, and the block.

In the line experiment a galvanised wire was stretched between two stakes driven into the sand in the deeper pools of the moat. Positions were chosen where there were already growing members of the sponge, and thus normal conditions were assured. The fragments, carefully cut from larger sponges, were attached to the line at intervals of 6 inches, being held in position by wire or by cord. Care was taken to see that the fragments were so placed that at no state of the tide did they touch one another, or the surface of the water or the bottom of the pool. It was found that if the fragments touched the surface for any length of time the persistently exposed portion soon died, became overgrown by filamentous algæ, and later the whole sponge was killed by the weed; and in the cases where the sponge touched the sand shells and sand became incorporated within the fibres and sometimes a small crab made a large hole in the base of the sponge, thus depreciating the value of an otherwise good specimen.

In all cases of fragmentation care was taken to minimise squeezing or tearing of the sponge during the cutting process, so that a sharp scalpel made of rustless steel was the first essential. The average size of the fragments was 9 by 13 cm. in two (horizontal and vertical) circumferences, though many smaller pieces were used and some were larger.

After the pieces had been planted out for some days, it was found that they became coated with a fine sediment which it had been the custom to clean off by gentle rubbing. This action would appear unnecessary, because all naturally occurring sponges have this fine coating of sediment, and even harmful for those sponges so handled were soon attacked by filamentous algæ.

Growth was very rapid in the early stages. In one day most of the pieces had coated their exposed and freshly-cut surfaces with the black "ectoderm," and in ten days those fragments held by cord had completely covered the material. This applies to pieces that had been given the maximum of ectoderm, but it was much slower for pieces with the minimum. In no case did the fragments with no ectoderm survive. In fragmentation, then, care must be taken to give each fragment as large a supply of the black ectoderm as possible. In six months (part of which time was winter) pieces of 9 by 13 cm. had increased to approximately 13 by 17 cm.

In the house experiment the object was to discover not only a suitable structure, but also whether in the absence of direct sunlight growth would be more rapid. The house was composed of the following parts and is depicted in photograph 3:—

Base of cement, 1 foot square.
Central pillar of 1 inch. hardwood.
Bamboo spikes.
Top of wood, 1 foot square.

Into the central pillar were fixed three tiers of the bamboo spikes, four to a tier. On to each of these spikes were placed two fragments so that there were twenty-four pieces to a house. Each fragment was approximately a 2-cm. cube when placed out, and in six months the pieces had grown to spherical masses of perfect form 11 cm. in circumference.

One house was left in the moat as a control, one was placed in a channel three to four fathoms deep on the north side of the sand cay, and one in five fathoms on the south side. It was found that those sponges on the lower tier of the house left in the moat died off, but those on the other tiers were quite healthy. All died in the houses that were placed out in deep water. A similar experiment with sponges found in shallow water on Murray Island, in which the deeper-planted sponges died, shows that this sponge is essentially a shallow-water form. Its farming is therefore a simple matter, while the collecting of samples can be accomplished by wading at low-water, the depth of the water in the moat at Low Isles being nowhere deeper than knee-deep at low tide.

A second type of house was constructed so as to float at the surface, with the sponges so placed that they were protected from direct sunlight but always covered by water. This house was lost during the heavy seas that accompanied a cyclonic disturbance in February, 1929. Owing to the likelihood of the recurrence of such disturbances in this area, floaters are not advocated and so the scheme was not persisted with.

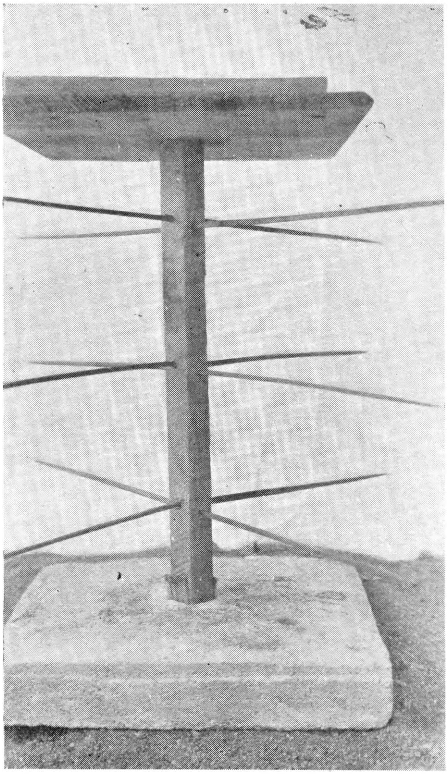


FIG. 3.—THE HOUSE USED IN THE SHADE EXPERIMENT. THE BAMBOO SKEWERS WERE SEVERELY ATTACKED BY TEREDO.
[*Photo., F. W. Moorhouse.*

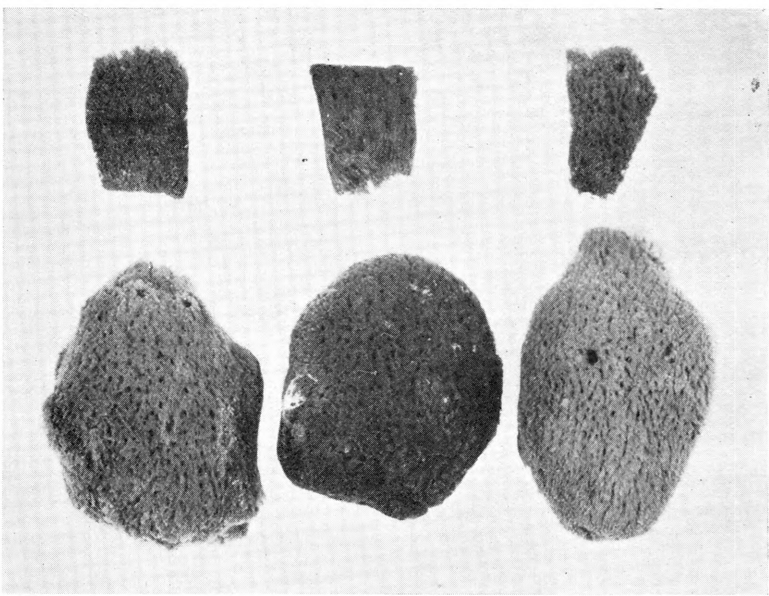


FIG. 4.—SPONGES OF PERFECT SHAPE GROWN FROM CUTTINGS AFTER 18 MONTHS. THE FRAGMENTS WERE PRESERVED AT THE TIME OF PLANTING OUT.
Face page 33.] [*Photo., C. Illidge.*

The final type was the block. This was a cement block 1 foot square and 2 inches thick into which ten bamboo spikes were so placed as to allow at least 3 inches between the fragments that would be placed on each spike later. Blocks were set out in deep pools of the moat with one piece of sponge to each spike, and when left all were in good health and growth had been as favourable as in the other plantings. On returning to these sponges after eighteen months, it was found that they had grown into well-formed sponges as shown in Plate V., fig. 4. Alongside the specimens have been placed for comparison typical samples of the pieces used preserved at the time of the planting-out. Growth had been as favourable as in those specimens protected from light, so that in so far as this sponge is concerned, there appears to be no advantage in protecting the fragments from direct light.

The wooden spikes used in these experiments had all been severely attacked by Teredo, so that the use of wood is not advised.

The simplest method of fixing out fragments is the line method, for it is inexpensive and lasting. Furthermore, fragments can be rapidly planted out. In this method a heavy gauge galvanised wire makes a serviceable line, but as it rusts slowly it will have to be replaced at intervals. ''Staybrite'' or other rustless steel wire is now procurable, and it should be eminently suitable for the work as well as for fixing the sponges to the line. The initial outlay will be amply repaid because the wires will last indefinitely and can be used again and again, and there will be no losses owing to the breaking away of the pieces.

The brown discolouration at the base of the sponge can be eliminated by chemical treatment which, carried out with care, does not impair the general qualities of the sponge, but gives to the sponge such a colour as to cause favourable comment from leading merchants of Brisbane who have seen samples.

Tressler, in *Marine Products of Commerce,* gives the process for the curing and bleaching of sponges as well as the strength of the solutions generally used in the sponge trade. It was found that the strengths of the solutions given by him are not suitable for our sponge. The bleaching solutions recommended for our shallow-water sponge are:—

(*a*) 5 to 10 per cent. hydrochloric acid solution.

(*b*) 2 to 3 per cent. potassium permanganate solution.

(*c*) 10 per cent. oxalic acid solution.

The process, with the approximate periods that the sponges should be allowed to remain in the solutions, is as follows:—

1. After the sponge has been cleaned of all living tissue by macerating in water, it should be soaked in the hydrochloric acid solution till all grit has been removed from among the fibres. The time varies here according to the amount of coral fragments present. Wash thoroughly.

2. Place the sponge in the potassium permanganate solution till it has taken on a uniform dark-brown to black colour. This takes but a short time. (*Note.*—The solution should be discarded as soon as it has lost its bright colour and become brown.) Now wash sponge thoroughly.

3. Place sponge in oxalic acid solution till the dark colour given to it from the potassium permanganate treatment has disappeared and the sponge has a faint orange colour. The time is again very short. Wash thoroughly and dry sponge.

The sponge is now ready for marketing, though Tressler recommends the soaking of the sponge in a caustic soda solution of about 10 per cent. strength for a very short period in order to dye it yellow. This process is not necessary for the Low Isles moat sponge as it possesses already a pleasing yellow colour.

Fig. 1.—The Breastwork, Looking North.

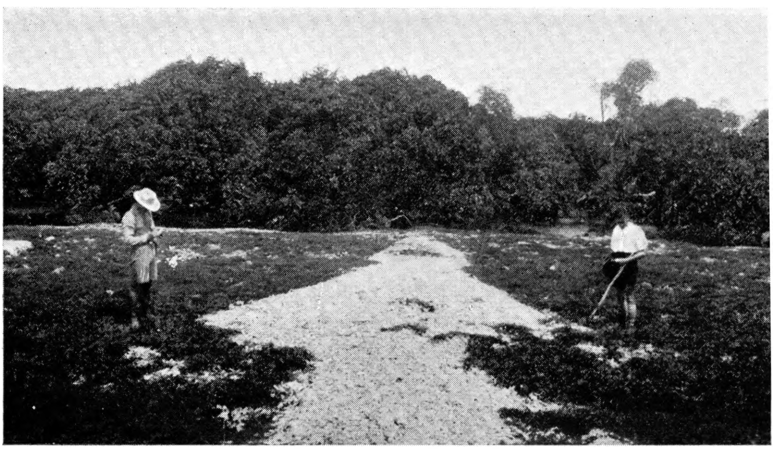


Fig. 2.—The Arrow-Head Deposit.

Face page 35.] [*Photos., F. W. Moorhouse.*

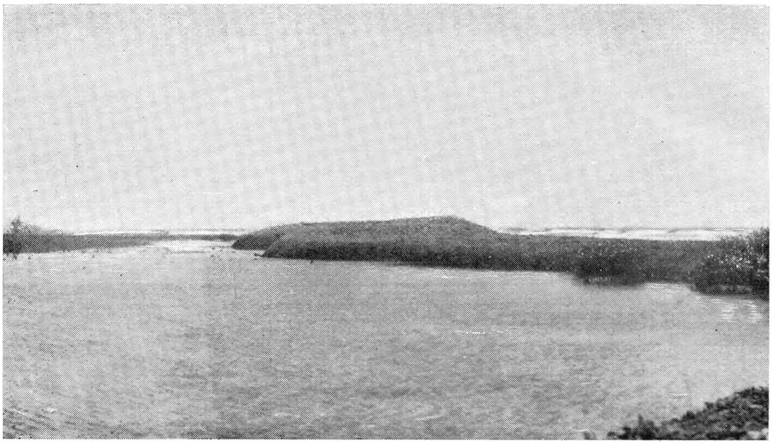


FIG. 3.—THE BREASTWORK, FROM THE SOUTH. NOTE THE WATER OF THE MOAT.

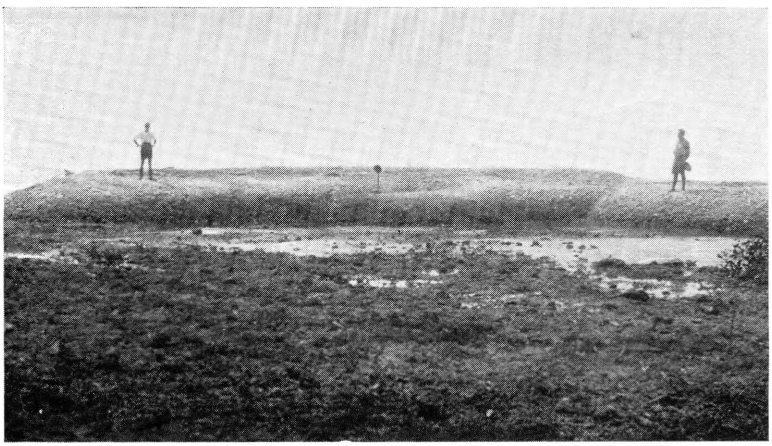


FIG. 4.—THE BREASTWORK, FROM THE MOAT.

 [*Photos., F. W. Moorhouse.*

No. 4.

THE RECENTLY-FORMED NATURAL BREASTWORK ON LOW ISLES.

By F. W. Moorhouse, M.Sc., late Marine Biologist to the Government of Queensland.

(Plates VI. and VII.)

In March, 1931, the writer visited Low Isles and noticed that much erosion of parts of the shingle rampart along the south and south-west edges of the reef had occurred since July, 1929. On the other hand, several parts of the shingle bank on the east-south-east edge were noticed to have increased in size; for instance, there were two large accumulations of much-worn coral fragments that had not been present at the time of the Great Barrier Reef Expedition's term on the island.

Each of these mounds possessed an elongate horseshoe shape, the horns of the shoe being towards the moat, *i.e.*, furthest from the wave line. The seaward faces of these much-flattened crescents curved gradually from the middle point for two-thirds of the distance towards the extremities and then the final portion ran back sharply and, losing height, became wide flattened low domes that tended to approach each other (Plate VII., figs. 3 and 4).

The slope of the deposit from foot to narrow crest was more or less gradual on the seaward face, but on the inner face it was steep and short. From the mid-point of the crest the slope along the crest was gradual to the flattened horn on the north, but on the south, though gradual at first, it terminated abruptly before running back to the horn (Plate VII., fig. 4).

The lengths of the horseshoe formations were 72 and 100 feet, respectively. The greatest breadth of the 72-foot accumulation, measured from the outside of the curve to an imaginary line joining the two horns, was 33 feet; but that of the larger bulwark was not easily determined as the horns faded gradually into the Sesuvium and there merged with the older deposits.

Between the two crescent ramparts a third deposit of newly-bleached coral fragments occurred (Plate VI., fig. 2). This stretched towards the mangrove moat and, covering the Sesuvium, gave an arrow-head shape to the strip. It is probable that a large uprooted mangrove that had stranded nearby had had its influence on the waves, and swirls had been set up that caused the elongate deposition of the fragments.

The feature common to all three accumulations was the clean bleached nature of the fragments of coral, the majority of which were derived from various species of *Acropora;* shells and driftwood were also present. The coral fragments on other parts of the shingle ramparts were dull-coloured and drab, against which the whiteness of the breastworks stood out conspicuously.

The accumulations appeared to be of recent origin, and this is borne out by the statement of Mr. M. O'Meara, the head lightkeeper on Low Isles, that it had been formed during the heavy weather that had been experienced during February.

Of the following information, given to show the conditions that prevailed at the times of the high tides that occurred in February, the wind and sea conditions were taken from the log of the lighthouse, while the heights of the tides are those given in the Tide Tables issued by the Department of Harbours and Marine and actually apply to tide that occurred at the Pile Light in Brisbane; those for Low Isles would be some 18 inches in excess of those given:—

Date.	Tide.		Wind and Sea Conditions.
	Ft.	In.	
2nd February ..	7	8	Flat calm to light westerly breeze.
3rd February ..	8	0	Flat calm to light breeze from west.
4th February ..	8	0	Calm to light northerly.
16th February ..	7	2	South-east wind of force 3 to 4 : sea moderate.
17th February ..	7	4	Squally south-east wind, force 4 to 5 ; sea rough.
18th February ..	7	2	Heavy south-east wind all day, force 5 to 6 ; sea rough.
19th February ..	7	0	Heavy wind from south-east, force 5 to 6, dropping to force 3 to 4 at night ; sea rough.

The accumulations therefore appear to have been formed during the heavy weather that was experienced in mid-February. Each was constructed by stages, for three crests at least were seen, each rising successively higher than the one before and culminating in the latest formed. Early crests are showing in photograph 1.

All three deposits were formed above neap tide high-water mark, so that only higher tides than these had any influence on the building of the bulwarks.

Frederick Phillips, Government Printer, Brisbane.

Reports of the Great Barrier Reef Committee.

VOL. IV. PART II.

No. 5.

THE CYCLONE OF 1934 AND ITS EFFECT ON LOW ISLES, WITH SPECIAL OBSERVATIONS ON PORITES.

By F. W. Moorhouse, M.Sc., Field Investigator to the Great Barrier Reef Committee.

(Plates VIII.-XI.)

1.—The Cyclone.

Sunday, 11th March, 1934, had not been a very pleasant day, and late in the afternoon rain squalls passed at frequent intervals over the island. The wind was from the south-east. The sky was lowering, but there were no indications of an unusual nature, the barometer standing at 29·62 at 9 p.m. Monday morning broke dull and squally, with the wind in the south. At 6 a.m. the tide was at the full, and it was observed to be at or about the same level as the highest tides of January. For an hour and a-half there was a slow ebb, the waters dropping a foot or so. Still nothing untoward had occurred, though the barometer was reading 29·06. It appeared as though the day would be very wet, but as such conditions had been experienced for over three months (25 inches of rain had been recorded for each of the months, December, January, and February), it was not surprisingly out of the ordinary.

At 8 o'clock, however, the wind freshened noticeably, and from then onwards it increased in intensity by gusts, heavy rain now falling in place of the drizzle. Each gust became stronger in intensity and longer in duration. Soon, leaves were being blown from the trees, to be followed later by twigs and branches. The waters, which, fortunately, had ebbed for some time were churned up, and large waves broke and pounded on the reef. The rain was now extremely heavy, and visibility was so reduced that objects but a short distance away appeared dim and indistinct.

The din of heavy rain on galvanised iron roof and of rattling iron and straining timbers was so intense that huge trees crashed or were broken off without being heard. As we watched, the close-by trees broke and went hurtling through the air. Large limbs were later found to have been carried hundreds of yards. It was not only the high trees that suffered—small ones, too, were torn out by the roots or broken off at varying heights.

At 9 a.m. the reading was 29·00, the lowest recorded. By 9.30 the wind was blowing from the east, but it had changed so imperceptibly that it had veered to this quarter without our realising it. There was no lull in the storm, the wind blowing with unabated fury and changing direction gradually till it came from the north-east. Later we read that the storm centre had passed a few miles to the north of us.

The heavy seas driven by the earlier south-east wind met the force of the north-easter, and a jumbled surf resulted. Huge breakers, seen only on such occasions in these protected waters, smashed in foaming masses on the reef and added to the din. But stranger still was the considerable rise in the tide. The waters were now approximately 4 feet higher than at 6 a.m., so that 6 feet is a conservative estimate of the extra rise.

At 11.30, three and a-half hours after the first definite indications of the blow, there was a decided change. Though the wind was still high and the waves pounded noisily on the reef, the heavy rain had ceased. Noon saw a further improvement.

2.—Immediate Results.

To assist in the interpretation of the various terms and place names herein used, reference should be made to the Key Chart on page 23 of "The Structure and Ecology of Low Isles and Other Reefs," in the Scientific Reports of the Great Barrier Reef Expedition, Vol. III., No. 2. The changes are shown on Plate VIII. in this report.

In the late afternoon a walk was taken round the reef. The waters were still unusually high and, owing to the stirring up of the mud and sediment in the Mangrove Park and Swamp, exceedingly dirty. Large boulders were found to have been washed high up on the north-east beach, and large slabs of living and dead coral had been turned over and left inverted. Sponges, holothurians, gastropods, and several species of sea weeds were left high and dry.

Shingle ramparts were pushed inwards into the moats. The greatest change had occurred on the north-east face. Here the most severe churning had been experienced, for in the early part of the disturbance it was only rather heavier seas than usual that beat upon the outer faces of the reef. The shingle rampart that met the moat in a sharp escarpment had been carried inwards from 25 to 30 yards and flattened down considerably. This North-east Moat had been extremely rich in *Montipora* and *Hippopus*. Now not one living piece of coral was to be seen—all had been smothered by the invading shingle. Many of the clams had been rolled away. These animals, attached in their young stages but depending in late life on their weight to keep them in position, were later found piled up in the roots of mangrove trees that stood in their rolling path, jumbled together against large boulders, or scattered indiscriminately over the sandy flats of Porites Moat and the shingle mounds of Tripneustes Spit. The Shingle Mound, a feature of the reef since 1928 and probably earlier, was washed in over Tripneustes Spit, spreading as it went. It was so reduced in height that half tides covered it completely.

Along the east and south-east shores the high shingle breastworks, three in number before the cyclone, were all flattened and washed inwards over the Inner Rampart.

As stated, the trees of Mangrove Park and Swamp received a severe handling. In the swamp proper it was mainly those on the outer fringe that suffered worst, though many in the centre of the dense mass had branches and even their trunks torn off. The glades inside the swamp where the trees were tallest presented a sorry sight. Not a tree escaped. The majority were blown out by the roots, some were broken off, and of those that were left standing the larger limbs were missing and the smaller were completely denuded of leaves.

On the Cay the trees were likewise smashed; the coconut palms were uprooted, screwed off at varying heights from the ground, or left leaning at such a dangerous angle that they had to be chopped down; the deciduous *Terminalia catappa* were either stripped of branches that faced into the wind or broken off at the base.

3.—Results seen Later.

It was some two months later that the day tides became low enough to bare the reef flat and to expose the outer reef edge. In the centre of the Sand Flat is a small sandbank, F4 on the Key Chart, that stands slightly higher than the surrounding area. On either side of this bank, which now measures 50 yards in length and 15 in width, and which has the long axis north-east–south-west, there was shallow standing water. On this small area, where no clams had been at the time of the original survey, there were found sixty-five living *Hippopus,* though the population, judging by the number of shells, had earlier been ninety-four, twenty-nine individuals having been silted up. Slightly further to the east, and in a small bay that at low tides receives a trickle of water draining from the pools of the reef flat, there had been eighty *Hippopus,* but the number had been reduced to sixty by excessive silting. At Clam Spit, to the south of the Cay, the sandbank was dotted heavily with living *Hippopus* and with the empty valves of many dead. Here the death rate had been very high, for only eighty living specimens were present, though 118 empty pairs of valves show that the chances for the survival of the higher placed are very small indeed.

The areas mentioned are typical of the small sandbanks that dot the surface of the Sand Flat. A similar redistribution of *Hippopus,* with a high mortality in forms left in unsuitable positions, such as piled up amongst the roots of mangrove trees, was noticed in the Mangrove Park. Thalamita Flat, to the south of the Sand Flat, still carries enormous numbers of *Hippopus,* though probably many of the individuals found on the Sand Flat came from this area.

Other invaders of the Sand Flat were the corals *Acropora hebes, A. squamosa,* a very large boulder of *Pavona cactus*, several colonies of *Lobophytum,* and some large gastropods—namely, *Charonia, Megalatractus,* and the Helmet Shell, *Cassis.* The majority of the corals were dying, except at their bases, where tiny pools of water collected at low water. *Pavona* was the last of these to die off completely.

On the western edge of the reef, along the Boulder Tract, there had existed flourishing colonies of corals, large areas of *Acropora* predominating. When this area was visited a few straggling colonies were found. These were in positions between or in the lee of large boulders that had withstood the wave action and protected the corals from *Hippopus* and other rolling intrusions. Apart from these few large clusters some small detached isolated colonies of *A. exilis* were all that remained of this once prolific field of Acropores. The attached nodular forms, such as *Favia, Porites, Goniopora,* and *Meandrines,* as would be expected, were fairly plentiful, while the loose forms, such as *Fungia, Polyphyllia* and *Herpetholitha,* were very prominent. These fungiids, however, showed by their mutilated septa that they had received a very severe buffeting. No young attached fungiids were noticed.

Elsewhere, save on the south-east edge and in Madrepora Moat, the branching corals suffered similar mutilation, even decimation.

The lowering of ramparts and the deepening of outlets, especially at Gaps A, B, and D, had allowed the waters that were formerly retained at low tide as deep moats to drain away considerably. This, naturally, had a serious effect on those corals that cannot withstand protracted periods out of water. Already the exposed tips of *Pocillopora bulbosa* were dying off and bleaching. Even the hardy *Montipora ramosa* showed in patches a similar bleaching, though not to any marked extent.

A remarkable change was seen in Fungia Moat, but here the cyclone was not entirely to blame. Where large fields of branching corals had been present at the original survey now only a few nodular corals were to be seen. A large part of the area is bare sand over which hundreds of the spiny sea urchin, *Centrechinus* (*Diadema*) *setosa,* wander and feed. These animals undoubtedly assist in the maintenance of this clean area, but much of the trouble was caused by man, who had earlier scoured the moat in search of the Fungias, attached and detached, that gave their name to this locality.

The Cay was considerably altered, much sand being taken from the windward sides and deposited on the western or lee shore. The result is that high water mark is now within 6 feet of the building that served as a kitchen to the Expedition, and high tides now cover the area where aquaria were constructed in 1928. The concrete foundations of the "Single" and "Native" quarters were destroyed during the cyclone, and the waves now reach to what was the centre of the huts. The encroachment has been from 15 to 20 feet.

The west of the Cay has been added to, and to-day its sandy beach reaches out to the large boulders of the Boulder Tract. The Northern Moat has been reduced considerably in size by this silting up.

The six patches of beach sandstone, marked C 1-6 on the Key Chart, are still six in number, but the areas uncovered by sand of two of these patches, namely 3 and 4, have increased, in width as well as in length, and each now reaches to the sand spit F2. The Bank, F2, is still present, and separates 3 from 4.

The washing inwards of three breastworks of shingle that had collected on the South-east Outer Rampart and of the Shingle Mound at the north was followed by a building-up with fresh shingle. Within two months these three breastworks had been rebuilt, though considerably further inwards, and a fourth had made its appearance on the Eastern Rampart. The Shingle Mound in miniature was likewise rebuilt, and it was sufficiently high at most high tides to afford nesting ground in November and December for the crested tern. It was only the young from those eggs placed on the higher parts that were successfully reared, newly-hatched birds and many dozens of eggs being washed away from the lower extensions.

4.—Some Observations on Porites.

The effect of the lowering of the waters of the moats on the perforate coral, *Porites,* was some time in appearing. Massive forms of this coral were plentiful in Porites Moat, and prior to March many of the blocks had grown up to the then low-water level. Their upper portions had been killed by exposure, and they appeared as flat-topped platforms, dead across the top and alive around the edges. The dead tops were covered by microphytic algæ and sediment.

It was some four months after the cyclone before the first sign of distress appeared. It took the form of a definite change in the colour tone of a small zone of the uppermost polyps, approximately 1 inch in width. The zone completely encircled the living blocks immediately below the dead area, where that was present, and represented the further portion of the living coral now exposed at low water. Blocks that had not previously been affected but were now exposed showed the colour change over the whole of the exposed surface.

Gradually the colour change became more pronounced, and spotted areas, usually pink in colour, began to appear throughout the coloured zone. Later, the first signs of weed were noticed. In every instance these filamentous algæ were just discernible as small clusters on or very near to the spotted areas. Slowly the clusters increased in size and number, the larger collecting fine sediment amongst their strands. The infestation started in the uppermost region of the zone.

Not only was there a change in colour in this newly exposed area, but it also became rugose, though elsewhere the general surface of the living coral was smooth. When the tissue was removed from small chipped-off portions of the corallum the unaffected portions were seen to present regular junction lines between neighbouring corallites (Fig. 1). Calyces from the affected zone, however, possessed most irregular junctions, and the septa appeared deep-seated owing to the increase in the height of the theca (Figs. 2 and 3).

The polyps of the newly-exposed zone appear to become stimulated, and an increase in lime deposition follows. Owing to their irregularity, the added portions at first look and act like long, sharp-pointed spikes. The constant retraction of the polyps over these spines forces them through the coenosteum, and leaves them exposed. It is upon these exposed projections that the algæ subsequently settle. The settling is a slow process because the tissues of the polyps again cover the projections when expansion occurs after the return of the tide. As stated above, it was upon the upper part of the zone that infestation first occurred. As late as December—nine months after the disturbance—many of the rough areas in the lower part of the exposed zone were still free from algæ, whereas most of those in the upper portion were completely covered and in places dead.

In the early stage of infestation the polyps are still living. The algæ, by growth and further additions, increase in size, and soon are large enough to hold amongst their threads the coarser sediment, also, that falls upon them (Fig. 5). The sediment cannot now be removed by the polyps, so that from this time on they are doomed. Death ensues sooner or later.

The slow rate at which algæ establish themselves upon the lower portion of the affected zone is due to the fact that these areas receive, except on absolutely flat calm days, a constant wetting from the lapping of ripples. Retraction of the polyps over the peculiar growths is not so complete, so that injury is less frequently caused and spines are seldom exposed.

A flange or rim never developed between the algæ and any polyp, or group of polyps, belonging to the many affected adult colonies of *Porites* examined, though the edge-zone was usually clearly seen. Stephenson, in Vol. III., No. 3, pp. 132-134 of the Great Barrier Reef Reports, mentions that most of the young colonies of *Porites* (and of *Pocillopora*) which he reared had developed flanges in order to ward off encroaching algæ—a response, he states, to accumulations of fine sediment matted together by a microscopic growth of algæ. He considers, however, that the flanged condition is not normal, giving three reasons for this opinion. His figures 1-3 and 5-9, on Plate V., show this well-defined rim as an up-turning of the edge, and it was frequently developed between corallites that had fused.

Much has been written on the deleterious effect of falling sediment upon corals, but, as was shown by Orr and Marshall in Vol. I., No. 5, of those reports, the effect, in general, has been greatly over-estimated. In their experiments falling sediment alone was normally readily coped with by the adult coral. Here, again, it has been found that sediment plays but a secondary part in killing.

Generalisations regarding death from exposure at low water are not sound. Wood-Jones maintains that, as a rule, exposure does not kill, whereas Stephenson considers exposure of vital importance, mentioning in Vol. III., No. 7, of those reports several instances of deaths from exposure.

That exposure will kill some corals there is no doubt—*Pocillopora* is extremely susceptible, and quickly dies from desiccation—but perforate corals, *e.g.,* branching *Montipora, Acropora,* and *Porites,* and also many imperforate corals, live for very long periods, regularly undergoing the usual tidal exposure. *Montipora* and *Acropora,* in particular, are quickly killed by the greatly heated surface layer of calm water, though *Porites* in the same locality appears unaffected. I have examined specimens of these two corals after a series of hot, flat calms, the portions for an inch or so immediately below water level were killed and bleached, while the exposed tips and the lowest portions of the colony remained unaffected. This results in the formation of a narrow band of white separating the coloured living portions.

So far as the nodular *Porites* is concerned, it is shown here that this coral can and does withstand months of tidal exposure, and that it is the increased growth stimulated by this exposure that is ultimately the indirect cause of death. So rapid is the production of new polyps, and yet so irregular, that the newly-formed polyps, instead of forming distinct corallites, build complicated trabeculæ, and it is these masses that give the rugosity to the general surface. But the formation of these trabeculæ is not an unusual occurrence, for Stephenson has shown (Vol. II., No. 3, pp. 132-134) that they were also frequently developed by the baby colonies that he reared from larvæ. In his examples they had no ill effects, because his colonies were never exposed. But in situations where retraction over these lace-like masses is intense they are fatal to the coral, for the sharper pieces penetrate the tissues, and, projecting sooner or later, afford settling areas for algæ. Once algæ have become established sediment becomes the lethal factor, though the polyps still struggle for existence, death finally occuring months later, after their complete smothering.

Stephenson showed that though the polyps forming the trabeculæ retained their identity no distinct corallites could be distinguished. His photograph of the corallum is here reproduced by his kind permission (Fig. 4). I also found that many of the trabeculæ showed no traces of corallites (Fig. 2), though in others there were frequently as many as three new calyces (Fig. 6).

Summarising these findings, we have that death in *Porites* exposed at low water is due to—

1. Injury to the tissues caused by their retraction over peculiar spine-like processes that are developed on the theca.
2. The projections, developed by asexually produced polyps, afford, when exposed, growing areas for filamentous algæ.
3. The algæ collect and hold the falling sediment which cannot now be removed by the polyps.

ACKNOWLEDGMENTS.

I wish to express thanks to Professor E. J. Goddard, University of Queensland, for granting facilities for carrying out certain observations, and to Mr. C. Illidge for his assistance in photography.

[The Great Barrier Reef Committee is greatly indebted to the Surveyor-General of Queensland for the re-drawing for Plate VIII. of Mr. Moorhouse's sketch map based on the chart by M. A. Spender in the Scientific Reports of the Great Barrier Reef Expedition, Vol. III., No. 2, Plate I.—EDITORS.]

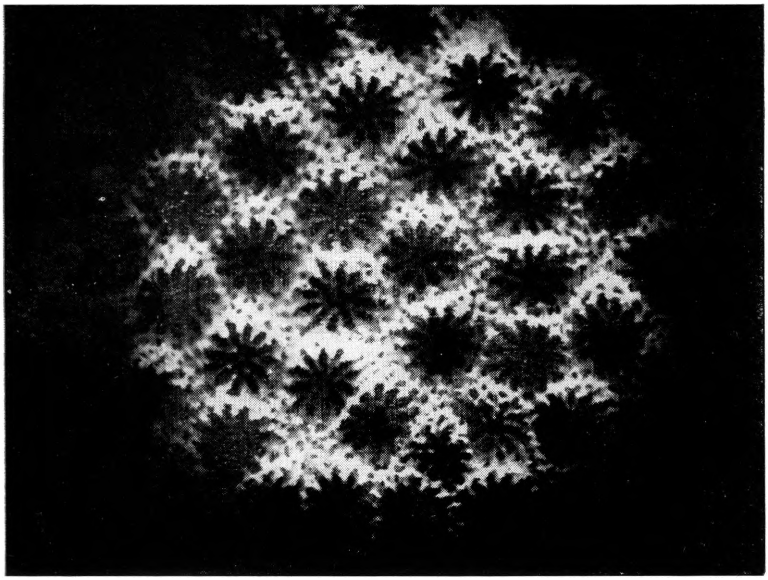


FIG. 1.

Photomicrograph of unaffected area. Corallites regular, of approximately equal size, with regular junction lines. × 12.

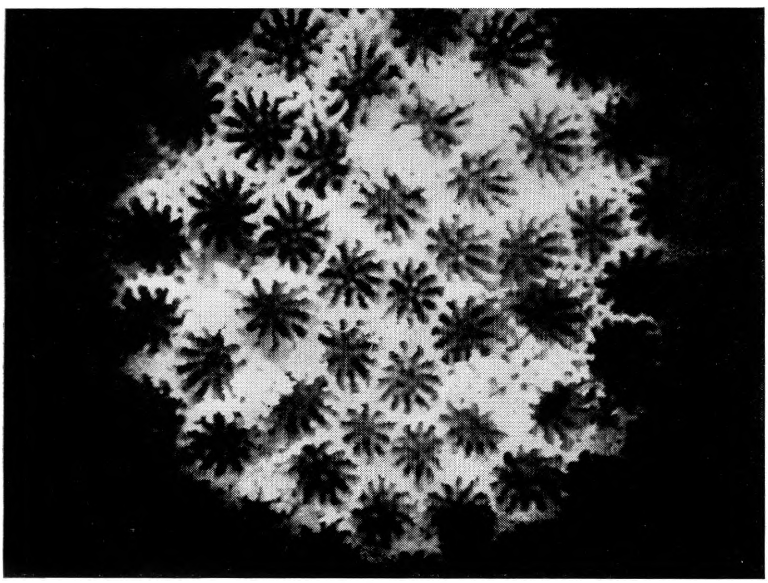


FIG. 2.

Affected zone. Corallites are irregular in size, and trabeculæ, much foreshortened, dot the surface. × 12.

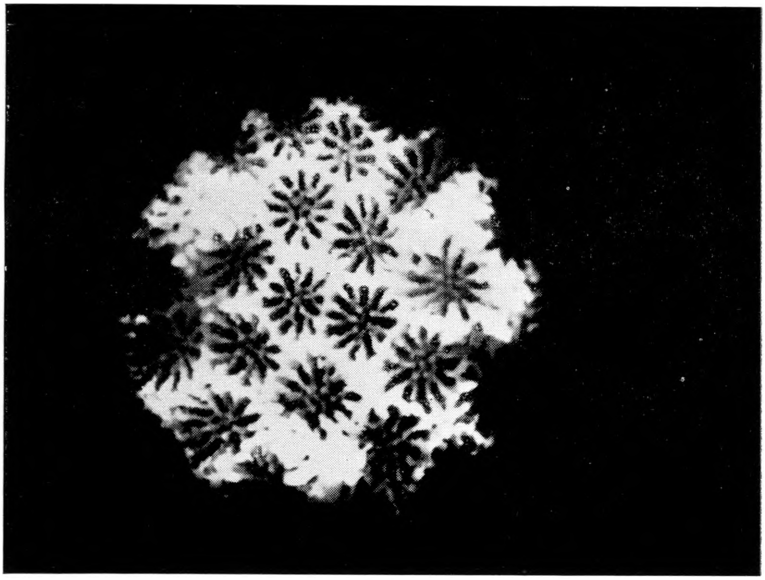


Fig. 3.

A closer view of trabeculæ. × 12. Their raised nature is lost owing to foreshortening.

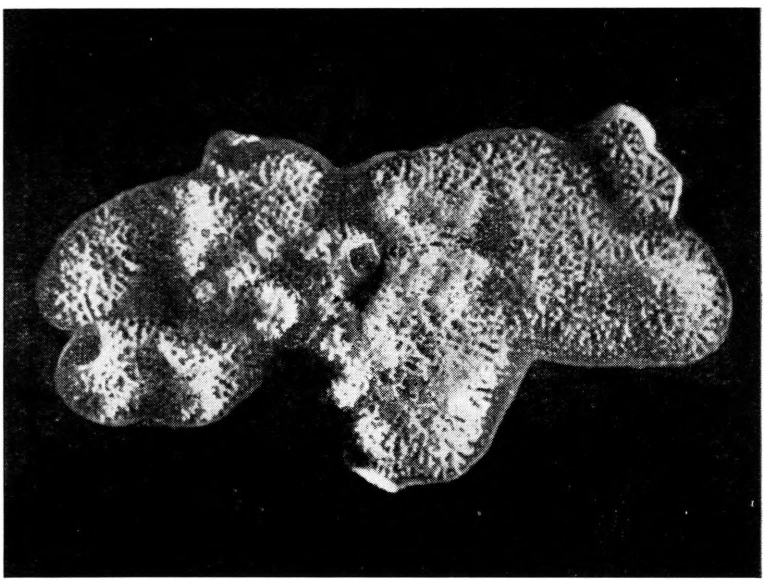


Fig. 4.

Photomicrograph of young colony of Porites reared by Stephenson, showing trabeculæ.

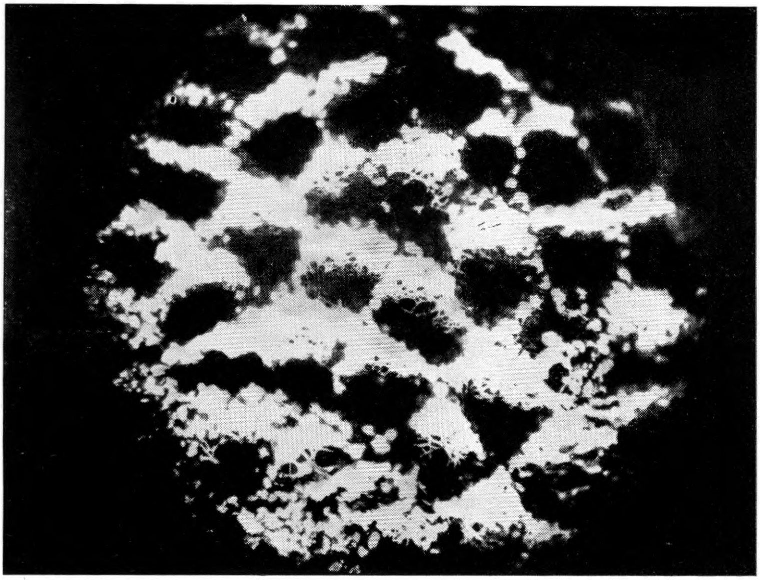


FIG. 5.

Microphotograph of zone showing algæ. The highlights are caused by collected sediment amongst the algæ. The polyps were still struggling for existence.

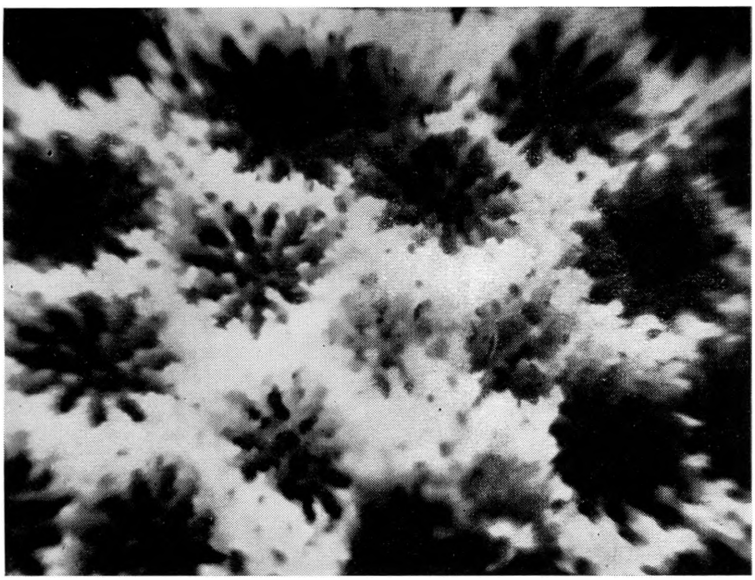


FIG. 6.

A close-up of one of the trabeculæ, showing three new corallites arising in the elevated mass. Surrounding corallites are out of focus owing to their being at a lower level. × 25.

No. 6.

THE SUPPOSED DEEPENING OF THE SEA FLOOR OFF BREAKSEA SPIT.

By W. H. BRYAN, M.C., D.Sc.

INTRODUCTION.

The supposed deepening of the sea-floor north of Sandy Cape has been referred to so often in the literature dealing with the Queensland coast and has assumed such an important place in theories of coastal evolution, both local and general, that the Great Barrier Reef Committee has asked me to place on record the real position of our knowledge with regard to the supposed change of level.

REVIEW.

Although Agassiz[1] had earlier referred to "the character of the soundings upon the bank indicating the former extension of Breaksea Spit," the first definite suggestion of major changes in the sea-bed in this locality was made by Hedley[2], whose statement is so important for the purposes of this note as to warrant its quotation in full: "A great bight occurs between Fraser's Island and Swain's Reef. A very remarkable instance of the recent retreat of the continental shelf was here discovered by Captain T. W. Sharp, of H.M.C.S. 'Iris.' Fraser's Island, Queensland, terminates to the northward in a prolongation called appropriately Break-Sea Spit. North of this, early navigators, among whom were Cook and Flinders, reported water of moderate depth. About 1869 this area was resurveyed and accurately charted by the British Admiralty. Repairs required by a submarine telegraph cable induced Captain Sharp to re-examine this district in 1904. He found that from 5 to 10 miles north of Break-Sea Spit the conformation of the sea-floor had entirely altered during the thirty-four years that had elapsed since the previous survey. Where his predecessors had found from twenty to thirty fathoms he measured from two to three hundred fathoms. The hundred-fathom line had greatly changed both in direction and position. Captain Sharp, who has most kindly supplied me with this information and the accompanying map (fig. 2), does not (as I am inclined to do) ascribe the alteration to a movement of the earth's crust. He believes it due to excavation of the sea-floor by a powerful southerly-going current. To quote his letter to me, 6/2/11: 'I consider the bottom in this locality to be liable to variation at any time not by subsidence but by currents, as it is entirely sand.'

"This change of the sea-floor extends over more than a hundred square miles. Alterations in the neighbouring coast might have been expected to have accompanied such great changes under the sea. But nothing to correspond has been noticed."

[1] A Visit to the Great Barrier Reef of Australia. Bull. Mus. Comp. Zool., vol. 28, 1898, p. 104.

[2] Proc. Linn. Soc. N.S.W., vol. 36, 1911, pp. 16-17.

David[3], commenting on Hedley's statement, accepted the evidence for "an extensive change in the continental shelf," but added that it was "probably due, in the opinion of Captain Sharp and myself, to excavation of the sea-floor by a powerful marine current." David continued, "As far as I am aware no earthquake shocks have been recorded from this region. This makes it improbable that the change of depth is due to bodily crustal readjustment."

Hedley[4], in his description of the Queensland Earthquake of 1918, stated that "Dr. Pigot calculated the epicentre of the earthquake as 1,180 kilometres (610 miles)* N.N.E. of his observatory. This pointed to a position on the continental shelf, north of Hervey Bay, and east-south-east of Keppel Bay. This place already has an interesting history; near here the submarine cables connecting Gomen in New Caledonia with Bundaberg have been broken so often that the route is now abandoned." With reference to the calculated position of the epicentre an erratum note[5] gives as the corrected position, "Lat. 24° S., Long. 154° E.; north-east of Hervey Bay; 980 kilometres nearly N.N.E. of Sydney."

Hedley[6] further recorded that the earthquake set up a long continued series of lesser shocks along the Leichhardt Range about 100 miles inland.

Hobbs[7] cited Hedley's original paper and added, "I am informed by Dr. Hedley in a personal communication that quite recently and since the later soundings were made the area has been the focus of a series of earthquake movements. The great importance of obtaining a new map of the area in even greater detail by the use of the sonic depth-finder after an interval of almost a score of years must be apparent to all." Hobbs regarded this as "an area of special unrest" due to its situation "upon the convex margin of a rising mountain arc."

Henderson[8], in a paper entitled "Subsidence of the Continental Shelf Northward of Sandy Cape," pointed out that in view of the interest of the problem, "the Australian Naval Board, at the request of the hydrographer of the Navy, gave instructions to H.M. Australian surveying ship 'Moresby' to rechart the position of the 100-fathom line in this locality, and the examination was carried out in May, 1927." From a comparison of the sea-bed as charted on this occasion with that of earlier surveys, Henderson concluded that a "very considerable change in the position of the 100-fathom line took place at some time between 1898 and 1904," and that "it must be remembered that a previous alteration in the position had occurred between the years 1879 and 1898. . . ." He added that "the 100-fathom lines of 'Iris' [1904] and 'Moresby' [1927] will be seen to be in close agreement both as regards

[3] Proc. Roy. Soc. N.S.W., vol. 45, 1911, pp. 57-58.
[4] Trans. Roy. Geog. Soc. Qld., vol. 1, 1925, p. 151.
[5] Trans. Roy. Geog. Soc. Qld., vol. 1, 1925, p. xii.
[6] Trans. Roy. Geog. Soc. Qld., vol. 1, 1925, p. 152.
[7] Proc. Amer. Phil. Soc., vol. 62, 1923, p. 73.
[8] Reports Great Barrier Reef Committee, vol. 3, 1931, p. 43.
* There is a discrepancy here, as 1,180 kilometres are approximately 733 miles.

position and shape of contour; it would therefore appear that no further breakages of the Continental Shelf have occurred since 1904." Henderson concluded: "It is not within the province of the present writer to advance any theory for this phenomenon, but it would seem that these investigations show clearly that there are considerable breakages of the Continental Shelf in the locality, and that these are non-periodic but of very considerable violence and extent when they occur. A further examination in a few years' time should prove of more than ordinary interest."

Davis[9] referred to Hedley's original pronouncement, and with regard to this "extraordinary increase in sea-bottom depth" stated that "it may be inferred that the advance of the Spit has caused an energetic scouring of the sea-floor beyond it."

The same author[10], in a later publication dealing with "Submarine Mock Valleys," placed considerable weight on the evidence from this area of what he termed "A Remarkable Example of Submarine Denudation." Davis wrote: "Both the pace at which the change has recently gone on in this instance and the depth to which it has reached are astonishing, so I wrote to the British Admiralty in London, asking whether the two sets of soundings in question [1879 and 1904] could be accepted as trustworthy, and was assured in reply that they could be so considered. This instance of rapid and deep submarine degradation would seem to be the greatest authentic example of its kind. Before accepting it as a finality, however, it may be prudent to wait confirmation by a third set of soundings, which should show a northward extension of the previously discovered deepening, if the explanation here suggested is correct."* Davis's suggested explanation has such a direct bearing on the subject under review and is, moreover, so important a contribution to the study of the growth and destruction of coral reefs that it may be advisable to state it in full: "It thus appears that Agassiz found that the sands, drifting northward, were smothering the corals at the end of the Great Barrier Reef, but that he had no knowledge of the deepening of the adjacent sea-floor, which had not been discovered at the time of his visit. Hedley, on the contrary, knew of the sea-floor deepening, but did not associate it with the smothering of the corals at the reef end, although he noted that 'conditions are really becoming very adverse for coral growth' thereabouts. But when the two groups of facts are considered together it is difficult not to associate them in the relation of cause and effect. It seems reasonable to suggest that, as long as corals and other reef builders thrive, the reef that they build will assume a submarine profile appropriate, on the one hand, to the constructive rate at which they contribute their calcareous skeletons to its building, and, on the other hand, to the destructive rate at which the local

[9] The Coral Reef Problem, Amer. Geog. Soc., 1928, p. 354.

[10] Geog. Review, 1934, pp. 302-304.

* Davis was apparently unaware of the survey made by the "Moresby" in 1927 and of Henderson's account thereof, which showed that there had been no northerly extension.

waves and currents wear the reef away. But as soon as the reef builders are killed the destructive waves and currents will have it all their own way, and a change toward a submarine profile of their preference will go on apace.''

The foregoing review may be summarised as follows:—

1. Important changes in the sea-bed to the north of Breaksea Spit have been inferred, the inference being based upon marked discrepancies shown by successive maritime surveys.

2. Two theories have been advanced in explanation of the supposed changes—

(*a*) The first regards them as due to important earth movements, and cites earthquake disturbances in the neighbourhood as supporting evidence.

(*b*) The second considers them the result of important submarine denudation, and cites a supposedly northerly migration of coral-smothering sands as a related phenomenon.

Examination of Evidence.

The Great Barrier Reef Committee, in 1934, realising the importance of securing a reliable statement on the supposed change in the sea-bed, wrote to Rear-Admiral Edgell, as head of the Hydrographic Department of the Admiralty, for an expert opinion on the matter. In reply Rear-Admiral Edgell despatched the following letter to the Committee:—

> ''I am sorry that your letters of 29th May, 1934, and 1st May, 1935, regarding the 100-fathoms contour north of Sandy Cape have been so long without an answer.
>
> ''Some difficulty has occurred in tracing information, without which a detailed reply was impossible, and pressure of work has prevented a careful study of the question as a whole.
>
> ''I have now been able to examine all the original surveys in our possession, compare results, and assess their value.
>
> ''To begin with, the so-called 1879 line of Bedwell is of much older date and is not Bedwell's work at all. This 100-fathoms contour is very poorly supported by soundings, which, indeed, are too scanty to warrant the drawing of one at all.
>
> ''The work was done in the years 1803-61, and though no record now exists of the methods employed to determine the position of the soundings, it is certain that the accuracy of the present day was not reached; indeed, the relative as well as the actual positions of Lady Elliot Island and Sandy Cape were different, and the land would not have been visible to afford a check by bearings. It seems safe to assume, therefore, that the position of soundings was determined by the dead reckoning or by observations of the sun, and that, in either case, having regard to the variable nature of the current and tidal streams, they could not be considered of much value.

"Bedwell's work did not cover the portion of the 100-fathoms line which is in question; some soundings taken by the cable ship 'Sherard Osborn' led to the 'Dart's' work in 1898, and Lieutenant-Commander J. F. Parry, who was then in command, recorded his conviction that the earlier soundings taken by Blackwood were erroneously placed.

"The 'Dart' was only able to spend one day on the work, but the weather conditions were ideal, and Sandy Cape lighthouse was in sight all the time.

"With regard to the work done by the cable ship 'Iris' in 1904 and 1911, it is difficult to estimate the accuracy with which the positions were determined; the soundings are probably correct within certain undefined limits, though their margin of error is unlikely to be great.

" 'Moresby's' survey is the only one which can be accepted without question; this was carried out under modern conditions and with the help of properly fixed floating beacons; moreover, the position of Lady Elliot Island and Sandy Cape were accurately known.

"To sum up, it does not appear to be safe to deduce that the differences in the various versions of the 100-fathoms line is due to changes in the sea-bed; there is far too great an element of doubt as to the accuracy of the earlier surveys, and, after most careful study of all available documents bearing on the subject, I have no hesitation in stating that in my opinion the 'Moresby's' work is the only survey which gives, or has ever given, an accurate picture of the sea-bed."

A critical examination of the other evidence cited in support of the supposed changes shows it to be equally unsatisfactory.

It is known, for example, that the submarine cable, the property of Compagnie Francaise des Cables Telegraphiques, which stretched from Bundaberg to New Caledonia, was broken on several occasions in the area under consideration, and finally abandoned after an interruption on 13th September, 1923; but such breaks are by no means rarities, and may be brought about by changes of the sea-bed far less important than those alleged in this instance.

Hedley has stated that the area is a focus of earthquake activity, but the evidence is far from convincing. Let us consider the facts—

1. During the interval between the surveys of 1898 and 1904, which showed the greatest discrepancies, there were no recorded earthquakes.

2. During the interval between the surveys of 1904 to 1927, which showed no appreciable change, there occurred the earthquake of 1918 cited by Hedley in support of his argument.

3. The position of the focus of this earthquake cannot be fixed with precision. According to the several possible interpretations of the

seismograph records at Riverview College Observatory, Sydney,[11] the distance from the epicentre varied from 980 to 1,180 kilometres (a difference of over 120 miles), while the exact direction from that observatory was also uncertain.

4. The after-shocks of this earthquake were 100 miles inland and nearly 200 miles from the area under consideration.

5. The only other important earthquake recorded from Queensland (that of 1935) was centred near Gayndah, 140 miles from the supposed changes in the sea-bed.

CONCLUSIONS.

1. In so far as all statements concerning the supposed changes in the sea-bed north of Breaksea Spit are based primarily on the comparison of maritime surveys, they are all nullified by the expert opinion from the Admiralty that only the latest survey ("Moresby," 1927) is reliable.

2. In addition, and in so far as the two alternative theories are concerned—

(*a*) The independent evidence of earthquakes on which Hedley's theory of subsidence relied is seen on analysis to be of very little worth.

(*b*) The critical prediction that Davis himself proposed as a test of his theory of rapid submarine degradation has failed.

3. The position as it stands at the present moment is that the alleged important changes have not been established, and that therefore all theories purporting to explain these alleged changes are gratuitous.

This is not a denial of the possibility that changes may actually have taken place. The verdict is "not proven." Consequently, and in view of all the circumstances, it would seem desirable that a further careful survey for comparison with that of the "Moresby" (1927) should be carried out (say, in 1937), in order to detect any possible changes that have taken place in the interim.

[11] Personal communication from Father Wm. O'Leary, S.J., Director, Riverview College Observatory.

DAVID WHYTE, Govt. Printer, Brisbane.

Reports of the Great Barrier Reef Committee.

VOL. IV. PART III.

No. 7.

DETAILED NOTES ON THE ISLANDS SURVEYED AND EXAMINED BY THE GEOGRAPHICAL EXPEDITION TO THE GREAT BARRIER REEF IN 1936.

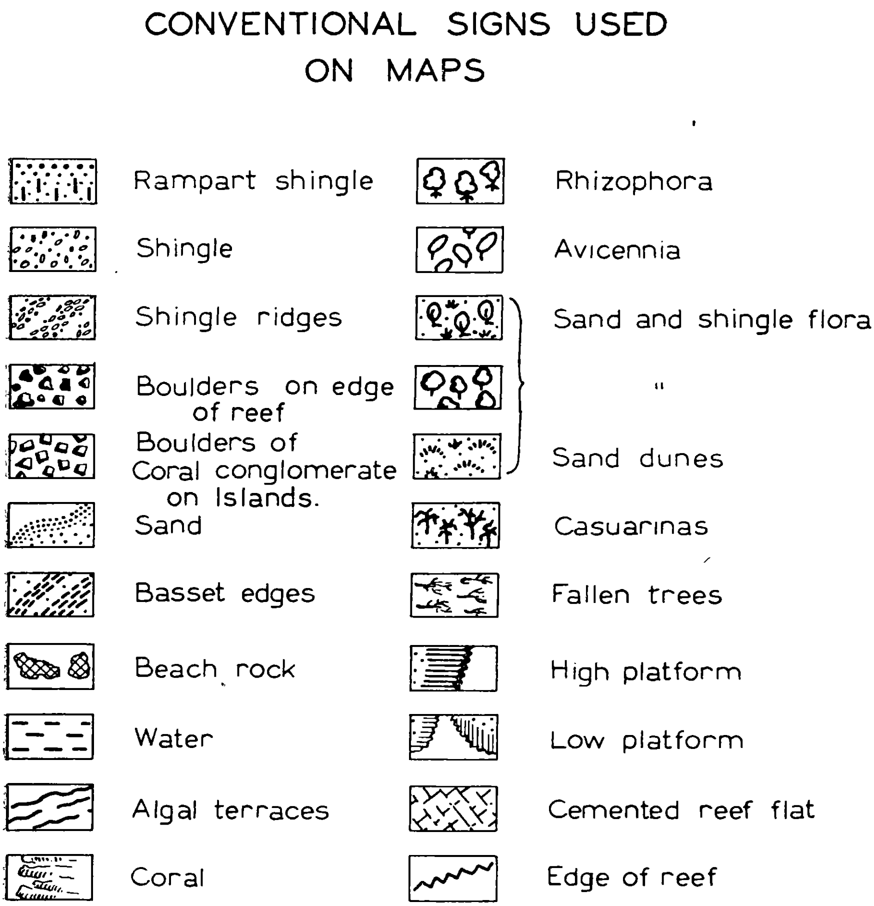
By J. A. Steers.

Introduction.

The following notes are intended to give reasonably full descriptions of the islands which were mapped. They should be used in connection with the corresponding maps.

The mapping was carried out by Mr. F. E. Kemp. Usually he had to be entirely responsible for the traverse, but some islands, at which we stayed rather longer, were chain-traversed, and then Mr. Histed, Mr. McNaught, or Mr. Porter helped in the work. The general direction of the survey was made by the writer, and Mr. Kemp soon became adept at making a reconnaissance map of the main physiographical features of each island. His services were invaluable. Naturally, in the three months available for the work it was impossible to spend long on any one island. As noted above, this meant that nearly all the maps had to be made by direct drawing in the field, measurements being made by pacing and bearings taken with a prismatic compass. It is no easy matter even to walk round a low-wooded island, and the small closing errors made in the traverses were a most welcome check on the work. Whilst, then, the maps do not pretend to be rigidly accurate, we were satisfied that they showed the general structure of the various islands adequately. A rigid survey would take a long time, because it is very difficult to obtain sights, and tidal conditions greatly limit the available time for working round the outer side of the mangroves and shingle islands. Probably a theodolite traverse would prove the most satisfactory means of mapping if time were available. The outer edge of the reefs as shown on the maps is generalised. Some of the Admiralty charts are on a sufficiently large scale for it to be taken from them. From others a rough enlargement had to be made, and critical points checked by pacing or estimation in the field. On the other hand, none of the intricate detail of ramparts, moats, platforms, &c., shown on Kemp's maps appears on the charts.

The reader should, then, bear these points in mind when using the maps. They are intended to show only the general structure of the islands, and to set their main features in an approximately correct relation to one another. Detailed measurements, except on those islands traversed by means of a chain and plane-table, should not be made. We fully realise that more detailed mapping will add to, and to some extent modify, our maps. This is inevitable, but we have every reason



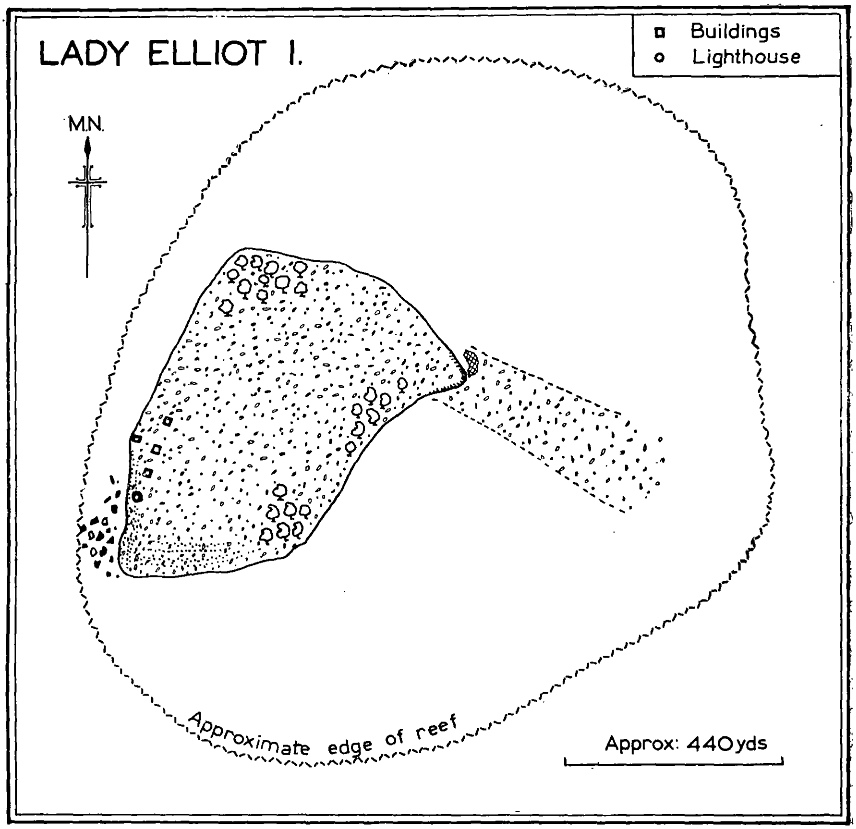
to feel that they will form a useful basis for more detailed work in the future.

One of our main objects was to obtain a clear notion of the variations shown in low-wooded islands. This implied seeing as many islands as possible. The notes given in this paper, and the discussion given in the two papers in the *Geographical Journal* for the months of January and February, 1937 (which should be read in conjunction with this account), will show that although differences do occur between islands, their general structure is remarkably similar. The work has borne out, and to some extent modified, that carried out by the Geographical Section of the British Expedition to the Barrier Reefs in 1928, and reference should, therefore, also be made to the earlier papers by the writer (*Geographical Journal*, Vol. 74, 1929, pp. 232-257 and 341-370) and also to the two papers and the excellent and detailed maps of Low Isles and Three Isles by M. A. Spender in the same journal, Vol. 76, 1930, pp. 193-214 and 273-297.

[Where not otherwise stated, the maps were made by ordinary compass traverses.]

N.B.—The following descriptive notes are arranged in the order of the islands from south to north—*i.e.*, from Lady Elliot Island to Chapman Island.

(Other islands were visited, but not mapped.)



NOTES ON THE ISLANDS MAPPED.

Lady Elliot Island.—This is a bleak, wind-swept island, and is the most southerly of the true coral islands. The map shows that it is about $\frac{1}{3}$ mile long, and approximately $\frac{1}{4}$ mile wide.

It is formed almost entirely of lithified coral fragments, and frequently the material is arranged in ridges which run more or less concentrically with the present outer rim of the island. Near the south-south-western corner the present outer ridge cuts across several inner and older ridges. The cyclone of March, 1936, appears to have been responsible for building the outer ridge. The surface of the island is often bare; there are three isolated clumps of wind-swept trees, and elsewhere a thin covering of grasses and creeping plants. But, as the result of lithification and subsequent solution, karst-like features on a small scale have been produced.

The island is much closer to the west and south-west of the reef than it is to the eastern side, and in May, 1936, the outer ridge was best developed on the western side. This may have been caused by recent weather conditions, though it is at least possible that the waves on the eastern side lose part of their energy in traversing a wider stretch of reef.

It appears that a good deal of guano has been removed in the past, but the senior lightkeeper told me that little has gone in the last twenty-five years. I am unable to say how "official" this is. Superficially, there was very little fine material on the surface at the time of our visit. The whole island was formed predominantly of coarse coral conglomerate. The island also gives the impression of having grown around a nucleus. This, however, is normal, and is common to most islands in Barrier waters.

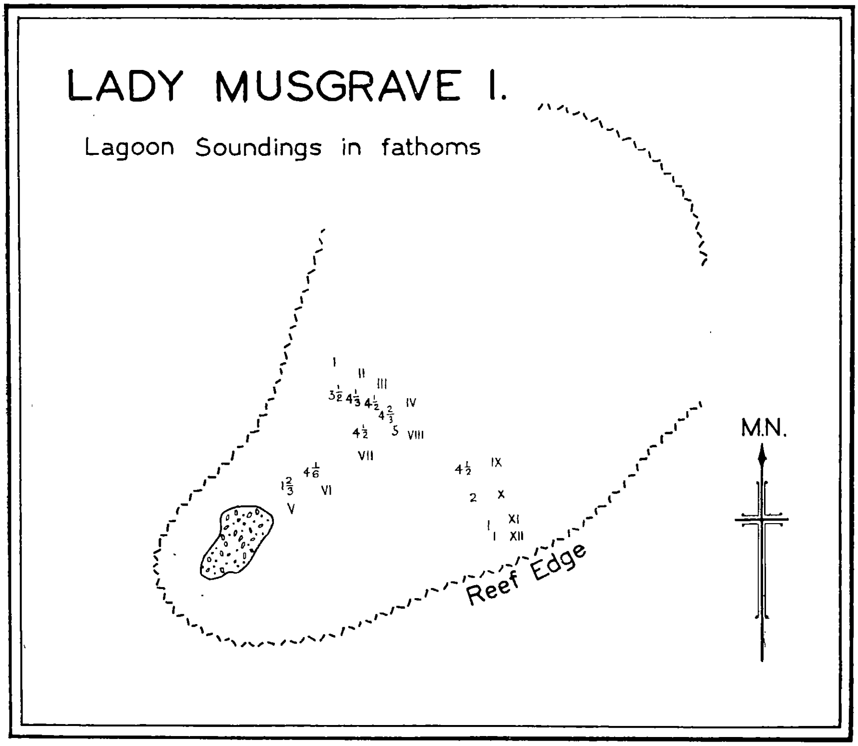
There was no feature on the island that suggested definitely any recent alteration of sea-level. The effects of waves under existing conditions are sufficient to explain the present features, especially when allowance is made for its exposed position. It may be remarked that the poor development of vegetation is probably as much the result of goats as it is of the wind. There is no lagoon; the island stands on an ordinary reef-flat.

Lady Musgrave Island.—The map of this island was made by means of a plane-table and chain traverse.

In May, 1936, it was thickly wooded, and the tangled undergrowth made direct levelling or cross-traverses impossible unless far more time was spent on the island than was available.

The island is composed of sand and coarse fragments, the latter predominating. In several places old "floors" of hard, lithified conglomerate occur, and show dip and strike quite well, thus indicating the origin of these "floors" as a series of ridges. It is probable that these places are those from which guano has been removed. The present beach consists mainly of finer fragments and sand, but erosion has cut away some of the eastern and south-eastern parts. This is shown by direct erosion of old beach-rock and conglomerate, and also by the uprooting of *Pandanus* palms.

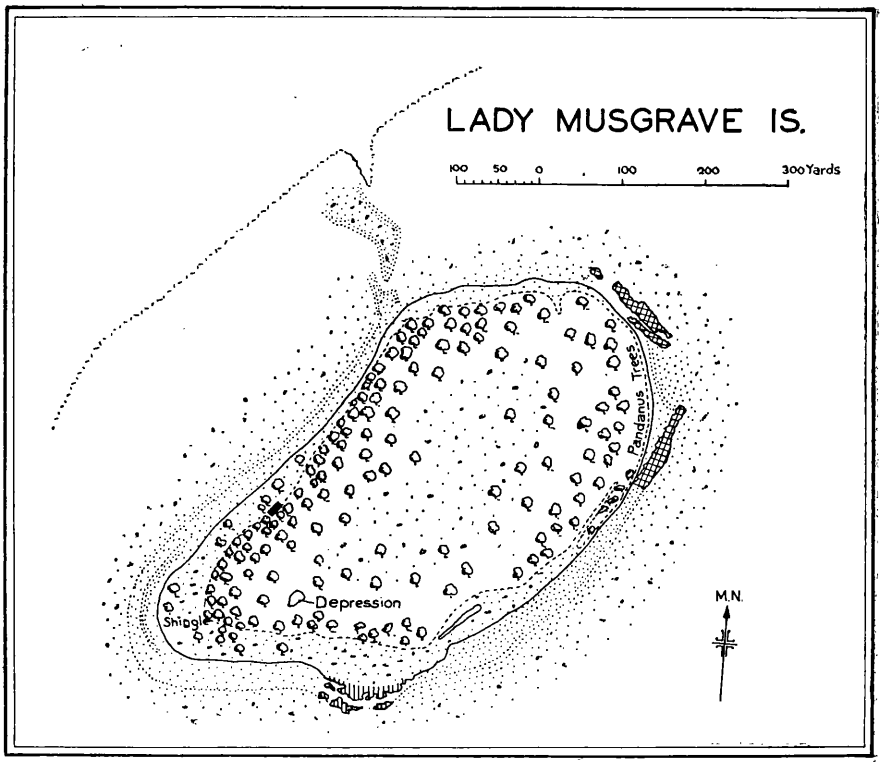
An interesting feature occurs near the south-eastern corner, where there is a platform-like mass of beach-conglomerate. The top of this is approximately level with the general surface of the island, but large masses have been eroded from its seaward face. Although in some ways it closely resembles platforms which are claimed as indicating a change of sea-level in the northern parts of the Barrier area,



it seems more probable that this particular feature only represents material which has been piled up by waves at present levels, then lithified, and finally eroded. The relatively exposed situation of this island makes a direct comparison with the Low Wooded Islands false. On the other hand, it must be stated that in parts the surface of this platform is grassed over, but the infrequency of storms directly attacking this particular point and sweeping over the platform is probably sufficient to explain this fact.

In general appearance the island, at first sight, is unlike Lady Elliot Island, but if Lady Elliot Island were afforested they would be very similar. A few years ago there was much less vegetation on Lady Musgrave Island; the change has been brought about by a considerable reduction in the number of goats. Within the island there is a good deal of brownish sandy soil, and at the south-western end there is a modern sand-and-shingle spit with *Casuarina* trees and some grass. This spit runs out to within a few hundred yards of the reef edge. The average level of the spit is similar to that of the island and of the south-eastern "platform"—another reason for not associating the "platform" with any recent movement of sea-level.

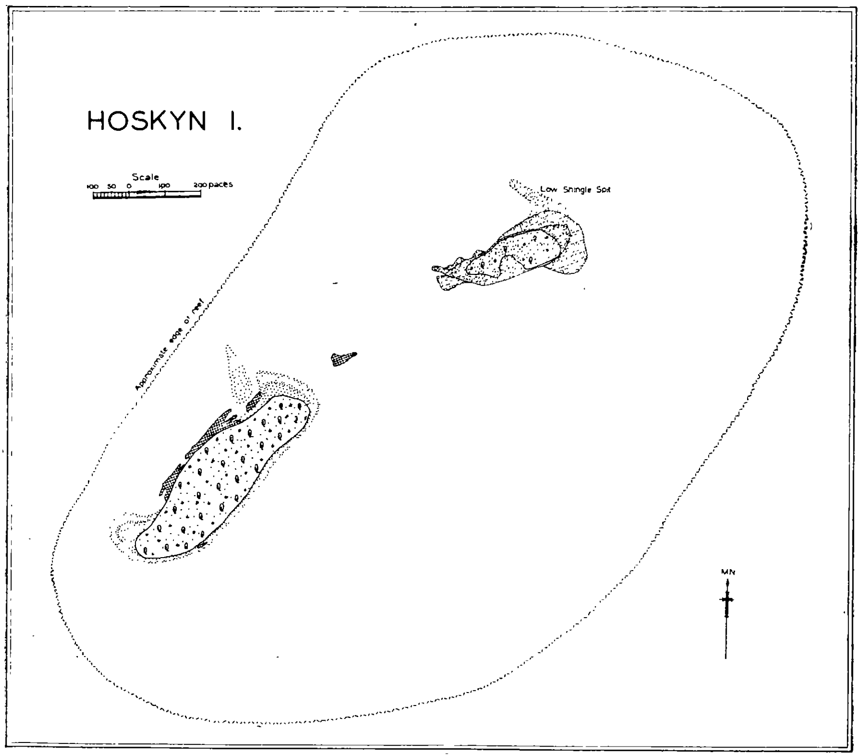
At the eastern and north-eastern end of the island there is a good deal of coarse beach-conglomerate, which, as shown on the map, juts out from the present beach and indicates by its strike and dip to the reef that the two main arms of this conglomerate originally enclosed a spit of sand or shingle. These patches were estimated to be 4 or 5 feet below the level of the top of the beach. Near the north-western



corner of the island is a long, flat spit of coarse, very rough, and quite unrounded coral shingle which runs out very nearly to the edge of the reef (see map). It is at a considerably lower level than the island proper.

The reef is interesting, and encloses a definite lagoon. There is a narrow passage through the reef which is said to have been made by Japanese fishermen. I have no definite information on this matter, but the passage is certainly narrow, and as far as appearances are concerned could have been formed in this way. As it is the only clear gap through the reef, and contains reasonably deep water, it is not easy to explain it on purely natural grounds. Various bottom samples were collected from the lagoon floor, and are described elsewhere. The lagoon floor consists mainly of fine, white coral sand, and in its deepest parts is 4 to 5 fathoms below water-level at low water. It shallows considerably to east and north-east, where numerous coral heads are found. The boulders on the reef are mainly concentrated on its south-western and northern parts.

The whole structure is, therefore, very like that of an atoll, but although the water deepens quickly outside the reef, it only reaches the normal depths existing on the East Australian shelf, and hence cannot be directly compared with a mid-oceanic coral island.



Hoskyn Islands.—(*a*) The Eastern Island—This is quite a small island built of coarse coral fragments which are often arranged in ridges. It stands well within the reef edge, and a rocky platform—the higher part only of which is shown on the map—runs from the island towards its larger neighbour. This same platform also extends around the eastern and northern sides of the islet.

The vegetation was thick and fresh, both big trees (one *Casuarina* trunk had a diameter of about a foot) and creeping plants being found. It is, as usual, most wind-swept on the south-eastern side. There is a relatively thick soil containing guano.

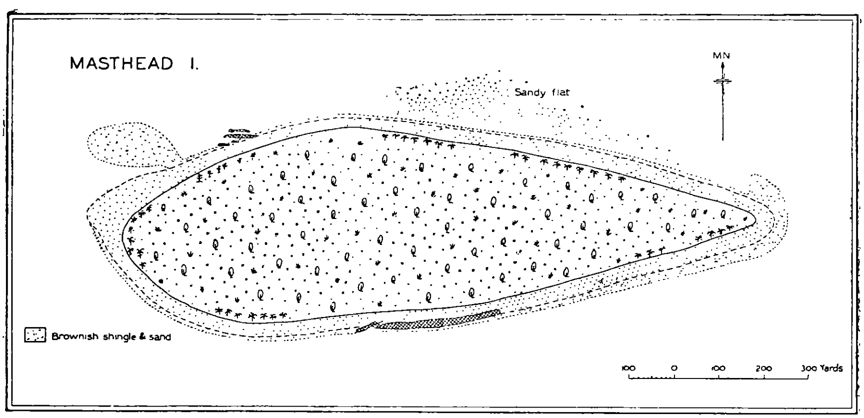
(*b*) The Larger Island—This island carries a thick soil and a dense vegetation. *Pandanus* palms form a nearly continuous outer belt. Within the island is a thick undergrowth of creeping plants, the creepers often growing over bushes in dome-like forms. The whole island seemed highly fertile, but our visit followed a rainy period.

The beach was not as steep as was usual on the Bunker and Capricorn Islands, and there was less coarse shingle on it. On account of the thick mass of plants it was not easy to make observations of the interior structure of the island, but in some places—more especially near the south-eastern end—the surface consisted of sand and coarse shingle. As far as could be ascertained from "explorations" in the interior and from a careful consideration of the exposed parts, there seemed to be definitely less coarse material here than on the two islands just described. There was a good deal of beach-conglomerate on the western beach, and patches of rather soft beach-rock on the east.

Between the two islands is a large patch of very jagged coral conglomerate rising up to about 4 feet above the average surface of the reef. The top surface of the conglomerate, though very rough in detail, was found to be fairly consistently a foot above colonies of *Ostrea mordax*. The strike of this conglomerate was roughly parallel to a line joining the two islets, and the impression forced upon one on the ground was that it represents all that is left of a former island.

The larger island stands on the south-western part of the reef, and thus conforms generally with the positions of most other islands of the Bunker and Capricorn Groups.

Masthead Island.—This was the last island visited on the return voyage. On account of bad weather conditions, about half of the



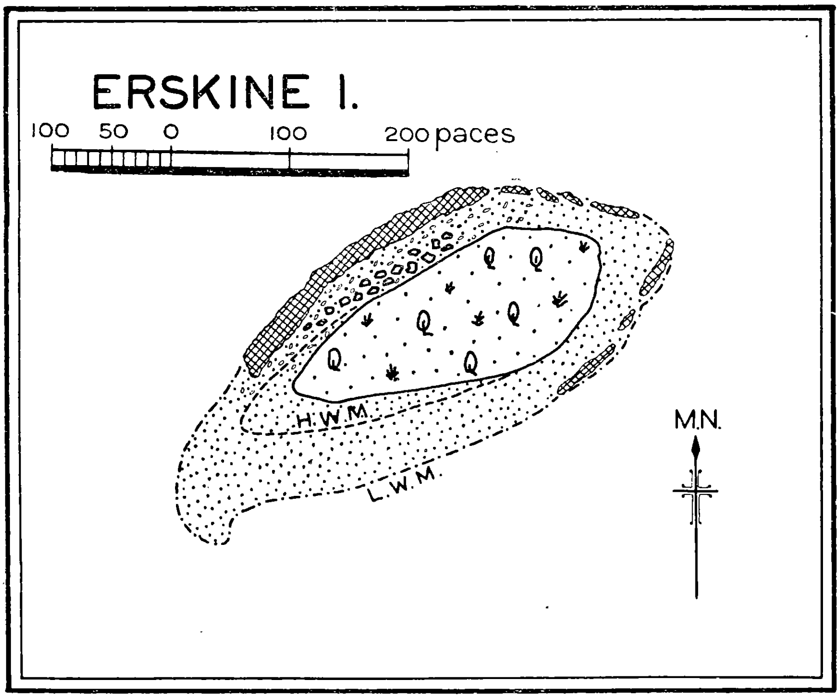
Bunker and Capricorn Groups were visited on the northern voyage; the remainder on the return. The only island not landed on was North Reef, but the writer made a short visit to that place in 1928.

Masthead is a large and attractive island which is composed almost entirely of sand. On the southern—the more exposed—side there was a fair development of flat-lying beach-rock, and a few old spurs of this rock were found near the north-western corner. The relation of these spurs to the present beach showed that certain minor changes have taken place in the shape of the island. This is quite usual, and only to be expected.

The vegetation is thick and luxuriant, so that the interior is rather difficult to penetrate. The weather side was "cliffed" along the dunes, and, on account of the sand blowing for the most part with the south-easterly winds, the rim of the island on the exposed side is rather higher than elsewhere. A good deal of recent damage had taken place at the eastern end of the island, and many well-grown trees had been uprooted.

The island was also mapped in 1923 by Professor Richards and Dr. Bryan by means of a compass traverse.

Erskine Island.—This is another sand island, and possesses no very striking or peculiar features. Like all the other islands in these two

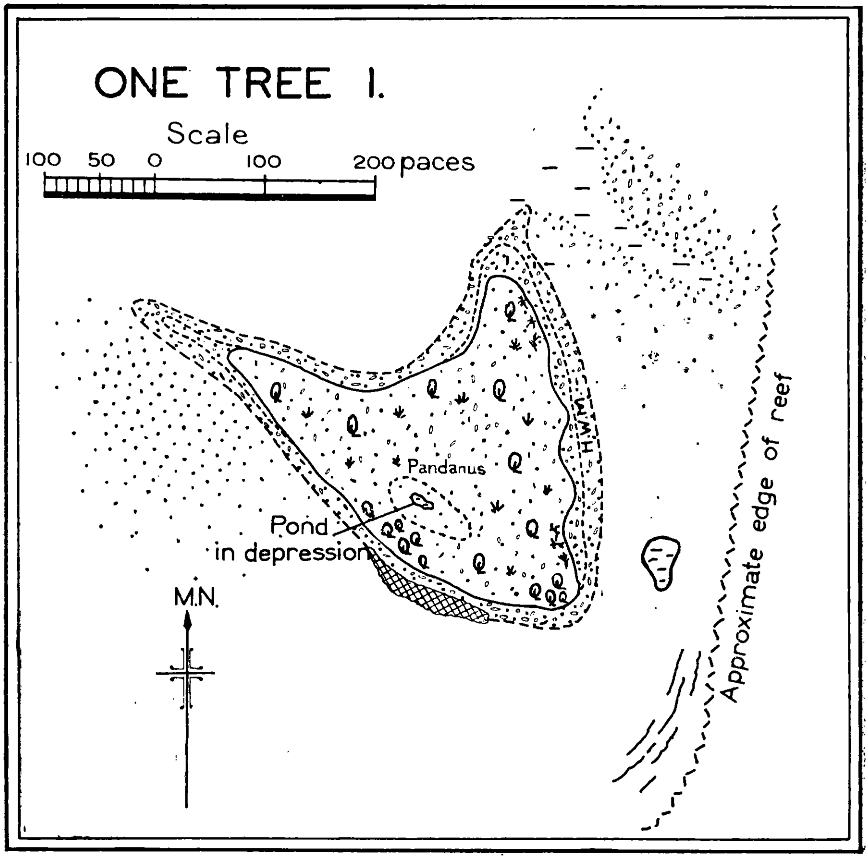


[A pace equals approximately one yard.]

groups, it is flattish in cross-section, the beaches being rather steep. Beach-rock is well developed on the western and north-western sides, and has been partly broken up by storms. In this way large boulders have been thrown higher up the beach, and give to it the appearance of a coarse boulder beach. There is also some beach-rock on the weather side, but much of this was buried under clean sand. The vegetation consists mainly of bushes of *Scævola* and *Tournefortia*, together with creeping plants and grasses. Though none of the bushes attain any height, the vegetation is thick.

A certain proportion of shingle and shell are also found on the beach, and there is some blown sand on the weather side. The island stands on a small reef and is a perfectly typical example of a sand island.

One Tree Island.—This is, perhaps, the most interesting island in the Bunker and Capricorn Groups, and is exceptional in that it stands

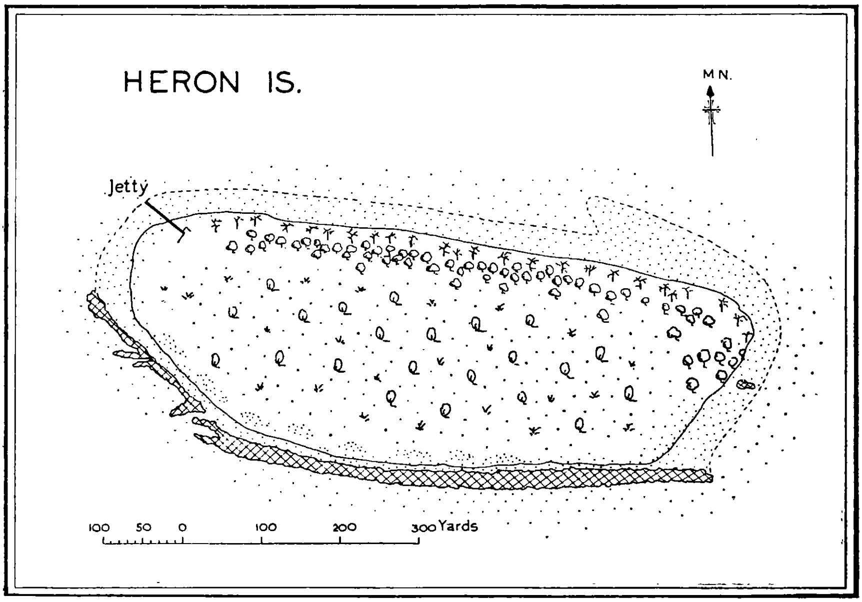


close to the weather side of its reef. The main island is formed almost entirely of coarse coral shingle, single blocks often measuring a foot or more across. There is also a proportion of finer detritus. The island really consists of a high outer rim, with some occasional high ridges running across it. Within is a depression containing (?) brackish water, which is surrounded by a dense belt of *Sesuvium*. On the south-western side some of the shingle boulders of the outer ridge have been combed down and form an apron which has subsequently been lithified.

This apron bears a striking resemblance to some of the coral conglomerate platforms of the low-wooded islands, but, as suggested above, has an entirely different origin. The vegetation consists mainly of low bushes and creeping plants and grasses, with a few clumps of bigger trees, which are very wind-swept.

The island stands on an extensive reef, much of which dries at low water, and is then seen to be largely covered with coarse shingle and large boulders. Nearly at the opposite end of the reef from that on which the island stands are some shingle banks piled up by waves and formed of medium-sized material. They were, in July, 1936, about 50 yards long, quite narrow, and awash at high water. Along the outer edge of the reef, from these ridges to the island, there is a continuous zone, some 300 yards wide, of coarse boulders and blocks standing a little above the general level of the reef flat.

Heron Island.—This island is formed almost wholly of sand. On the weather side (*i.e.*, the south and south-east) the sand has blown



into low dunes which are now held and almost covered by creeping plants, &c. *Casuarina* and *Pandanus* are also prolific on and near these dunes. On the seaward side the dunes are suffering some erosion, and are undercut along the whole length of the weather side of the island. On the other hand, on the northern and western sides there is a much more gradual slope from the beach to the general level of the island. There is no undercutting of the dunes on the lee side, and newly blown sand really formed a low frontal ridge rather than a complete dune. The south-eastern corner is a dune "bluff."

Along the southern shore, which was remarkably straight in May, 1936, there was a very good development of beach-rock. This is the normal rock—lithified beach sands with some scattered and small fragments of coral and shells. The strike of the rock is generally parallel with the shore, and has the normal seaward dip. On the western side of the island the beach-rock shows more interesting developments. There was a series of ledges of rock running more or less parallel to one another, and approximately in the same direction as the main mass on the weather side where the island turns to face the south-west (see map). These ledges often run back into the island, and suggest by their arrangement that they may each have formed earlier westerly extensions of the island. They also indicate that in this particular part the island seems to have prograded to the south and lost some of its former extent on approximately its south-western margin (one ledge of beach-rock dips in the opposite direction).

The island is fertile, and carries a dense vegetation with a thick undergrowth and some big trees, especially *Pisonias*. The soil is sandy, and there is a good deal of decaying vegetable matter and some guano.

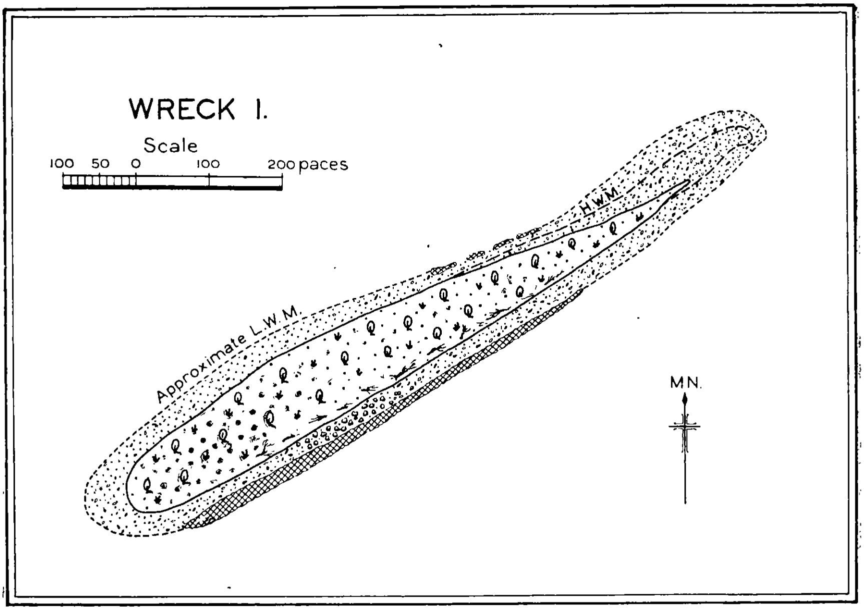
There is a permanent settlement (a descendant of a turtle-canning station) on the island, and several people stay there in the course of a year. It is a pity that the actual buildings do not harmonise with their environment.

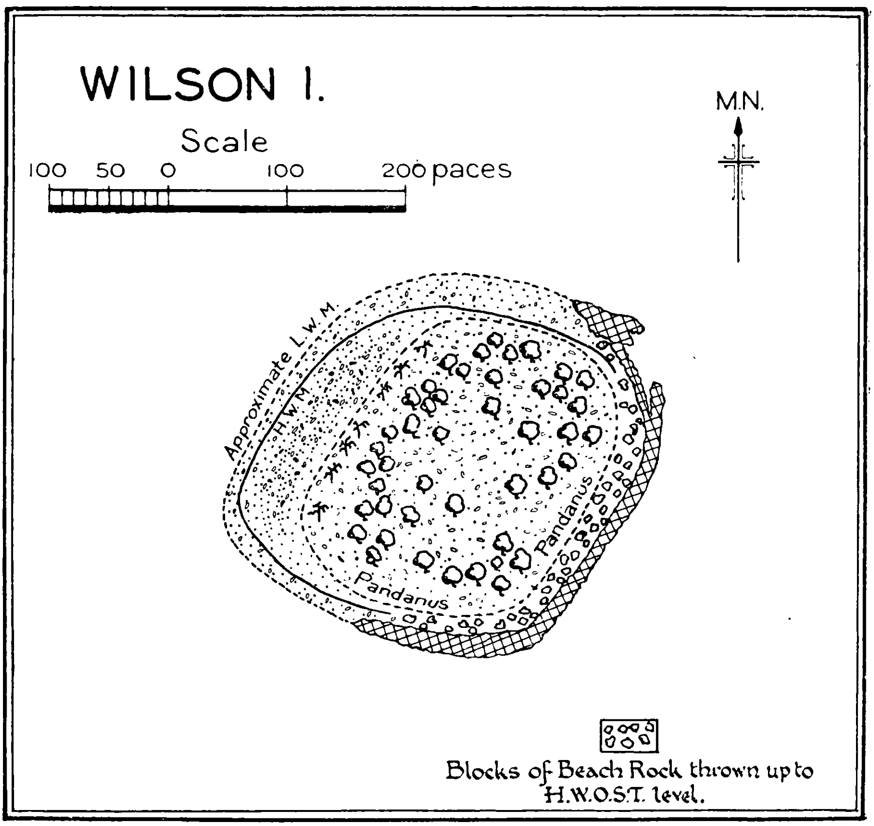
The island lies to the north-west of a large reef enclosing a more or less true lagoon. It was not possible to make soundings, but there appeared to be several patches of relatively deep water at low ebb. The island was carefully surveyed by a plane-table and chain traverse.

Wreck Island.—This is a long, narrow island, orientated roughly north-east and south-west. There is a good development of ordinary beach-rock along the weather side, and some small and disconnected patches on the lee side. A certain amount of that on the weather side has been broken up by storms and hurled higher up the beach, thus forming a zone of large boulders. It is, however, not so noticeable as it is on Wilson Island. The weather-side beach was mainly made up of sand with some fine shingle. Blown sand also forms a low range of dunes on this shore which shows signs of erosion.

At the north-eastern end the island passes into a long and narrow spit composed of sand and shingle. This part of the island is largely covered by *Scævola* and *Tournefortia*, but neither genus was in a very flourishing condition at the time of our visit (July, 1936). It was clear from the conformation of the spit that it had previously suffered a good deal of erosion, and that the distal part was a comparatively new growth.

The beach on the lee side was sandy, with many shells and a small proportion of medium-size shingle. The inner part of the island is thickly covered with plants and trees, *Tournefortia* and *Scævola* being the commonest genera.


WRECK I.
Scale
100 50 0 100 200 paces
H.W.M.
Approximate L.W.M.
M.N.

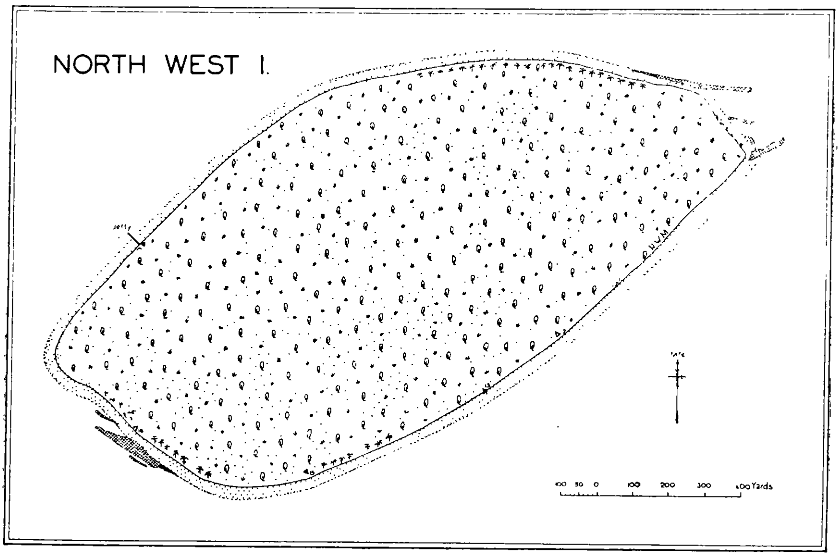

WILSON I.
Scale
100 50 0 100 200 paces
M.N.
Approximate L.W.M.
H.W.M.
Pandanus
Pandanus
Blocks of Beach Rock thrown up to H.W.O.S.T. level.

Wilson Island.—This is a small, oval-shaped island carrying a thick cover of vegetation. *Pandanus* palms are very common and form definite groves, especially on the weather side. The western side has clearly grown a good deal in recent years, the growth being shown by a series of roughly concentric sand-and-shingle ridges.

On the weather shore there is a marked belt of beach-conglomerate which has been much broken up by storms, so that large masses have been thrown above its general level and now form a ridge of boulders. The beach is steep on this exposed side, but although it is also high it is in conformity with the exposed situation of the island. The reef is a small one, and the appearance of the beach is again consistent with this fact.

Inside the island there is a good deal of sand, and a soil is forming. But there is also an abundance of shingle, which is usually coarse and arranged in ridges. The whole structure is thus a mass of coarse and fine material piled together, and so rather transitional, because it can hardly be grouped with the purely sand or shingle islands. It is also rather more compact in form than many of the Bunker and Capricorn islands.

North-West Island.—This, the largest island in the Bunker and Capricorn Groups, is formed almost entirely of sand. The interior was examined in several places, and always showed its sandy nature. There



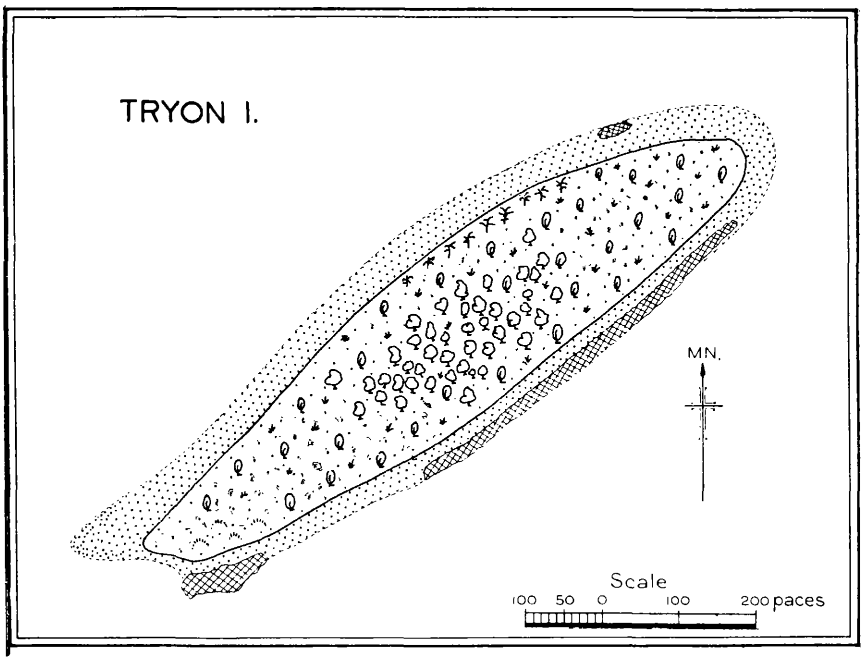
is some guano mixed with the sand and soil. The lee side has a normal sandy beach with some fragments of coral and numerous shells. The beach slope is quite normal (May, 1936), and showed no evidence of erosion. But at the eastern end changes have taken place. As shown on the map, there are horns of normal beach-rock which once clearly enclosed an extension of the island which has now been washed away. The only other visible patch of beach-rock at the time of our visit was at the south-western end.

The weather side of the island has suffered some recent erosion, which becomes increasingly noticeable towards the eastern end.

The island carries a thick cover of vegetation, but although the undergrowth is fairly dense it is usually easier to traverse into the island than it is on some other members of these two groups. *Casuarinas*, grasses, and an "open formation" usually occur in front of the main mass of trees. This corresponds roughly with the "esplanade" marked on the "official" map (obtained from the Government Surveyor's Office, Brisbane) of the island. On the other hand, the area on the island seems to be rather wider than indicated on the map. It was not clear why the word "esplanade" was used on the official map. Blown sand forms low dunes along the south-western side of the island, which is, therefore, a little higher than the average surface level.

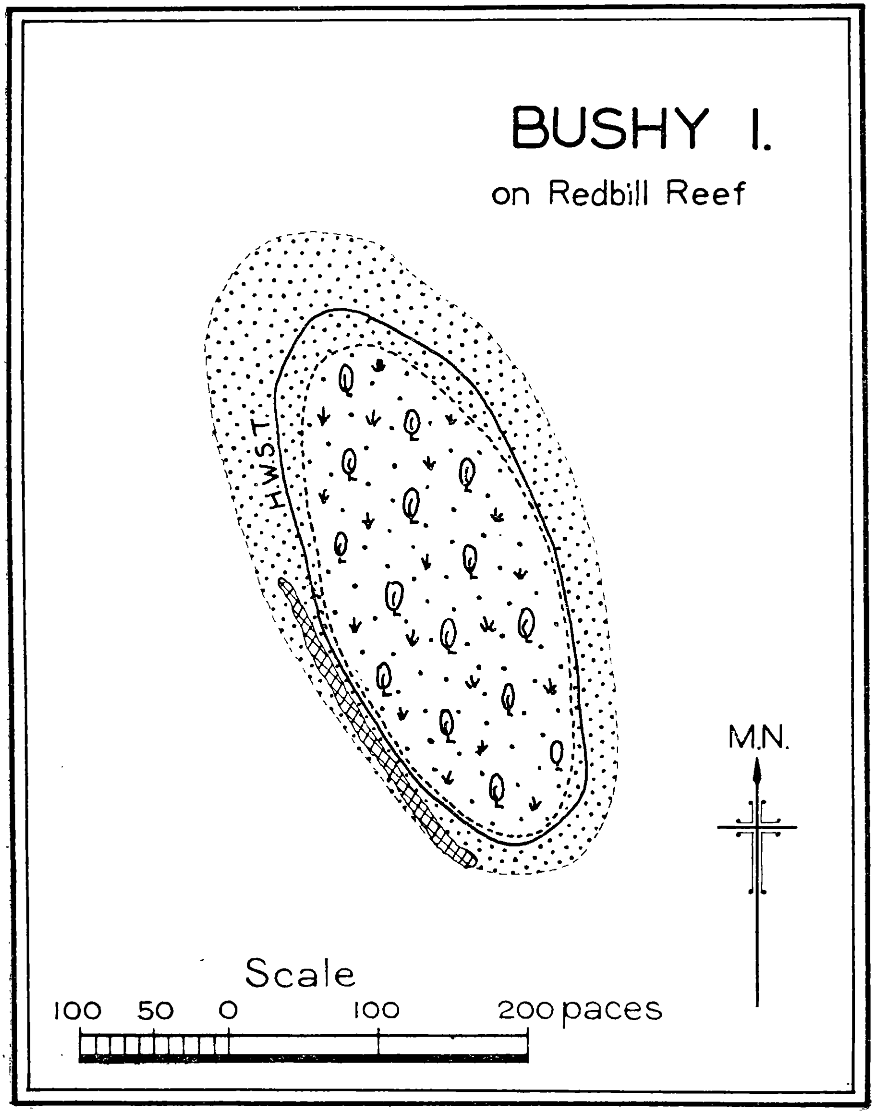
The present map was partly based on the "official" map.

Tryon Island.—This island was very roughly surveyed by means of a compass traverse. It consists almost entirely of sand and small



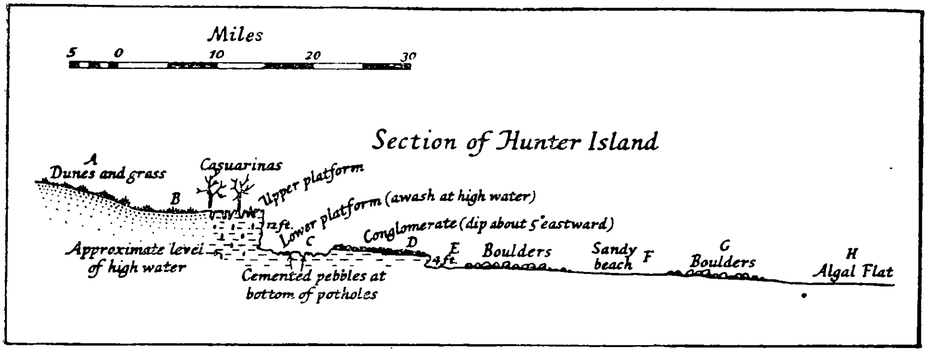
coral and shell fragments. There is some soil formation and guano. It is one of the normal sand islands, but a large number of coral pebbles and shells are found on its beaches. The vegetation is very thick, and there are many vines and creepers.

There is a long stretch of beach-rock along the weather side, and a certain amount of erosion is also happening there as well. There is an outrunning ledge of beach-rock to the south-west, and at the extreme south-west of this island is a modern sand spit and quite considerable

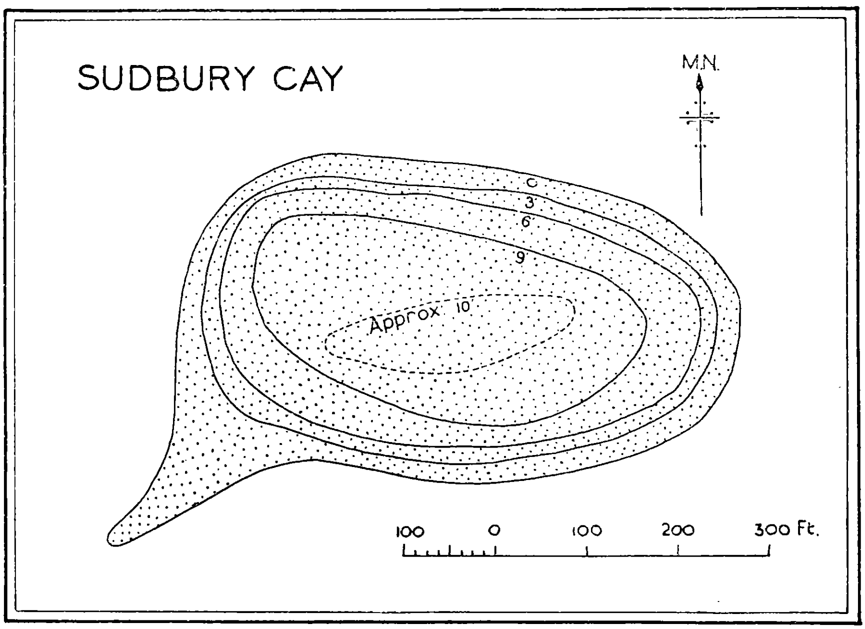


dunes reaching nearly 30 feet (estimated) above the reef-flat. This was the most pronounced dune seen on any of these islands, even though it was but small in area. The reef on which the island stands is a small one, and there is no lagoon.

Bushy Island.—Bushy Island and Redbill Island stand on a single reef. Redbill Island was not examined, but it is virtually an isolated rock around which a reef has grown. Bushy Island is, to all intents and purposes, a sand cay, and resembles the sand islands of the Bunkers and Capricorns very closely. Weather conditions made possible only a very brief visit to the island, but a rapid compass traverse was made. It



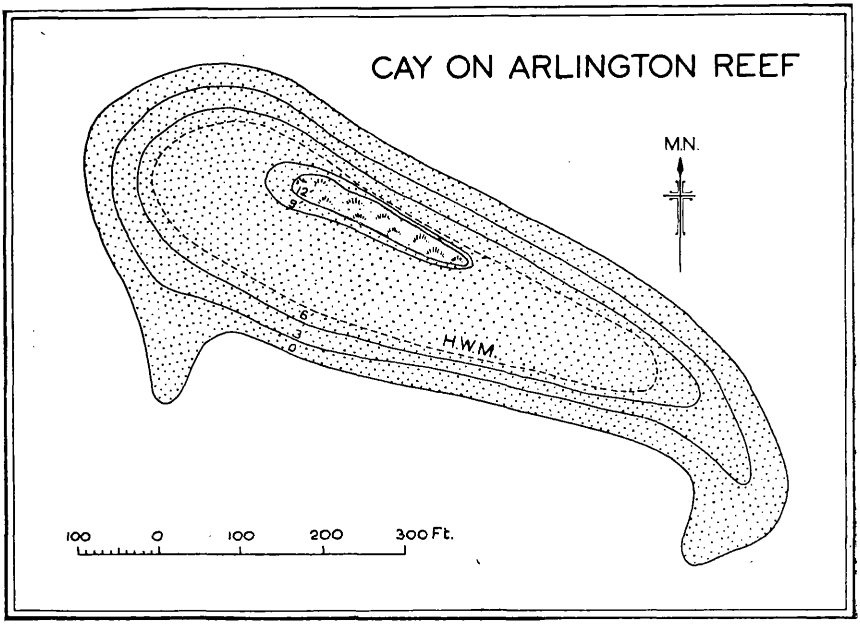
is a small island, elongated almost north and south, and stands on the lee side of the reef. There is a fairly close vegetation, including *Pisonia*, *Tournefortia*, and *Pandanus*. Creeping plants—*e.g.*, *Ipomœa*—were also present, as well as *Abutilon*. The whole island consists mainly of



sand with some scattered shingle. The south-eastern corner stood rather higher than the rest of the island, and the beach profile was steep in that place. Waves had recently attacked the southern end. Beach-rock was quite well developed along the south-western and western' sides. The general surface was fairly level, though there were some incipient ridges.

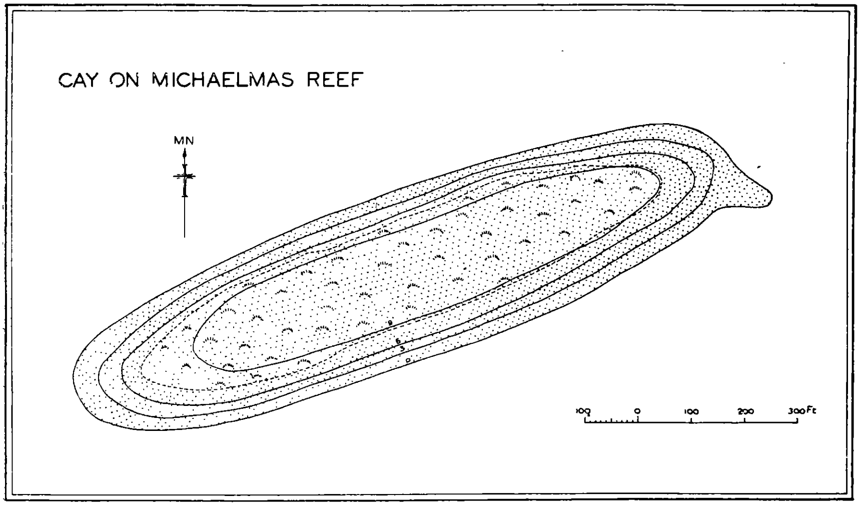
Sudbury Cay.—The simplest stage in island growth is seen in this cay, which is obviously liable to be swept away from time to time. In June, 1936, there was no vegetation of any sort on it (cf. 1928). It was merely a flat-topped heap of sand with occasional larger lumps of coral on the "beach." There was a short spit running towards the south-west; this was submerged at high water. In normal weather the top of the cay would probably be a foot or so above high spring tide level, but would be awash in a storm. As in all cays and similar islands, the line of separation between the sand of the cay and the reef-flat is a clear one. The contours shown on the map indicate here (and in other similar maps) heights above the average level of the reef surface, the lowest contour being virtually the edge of the sand.

Cay on Arlington Reef.—The only essential difference between this and Sudbury Cay is that this is in part covered by vegetation. The

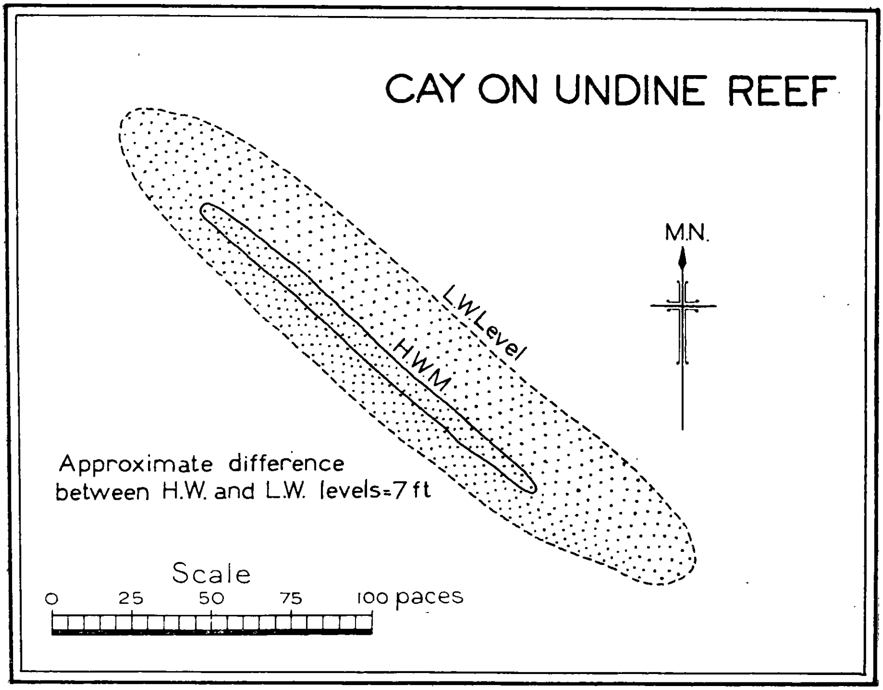


vegetated part stands rather abruptly above the rest of the island, but it is being cut into on all sides. The vegetation consisted only of grasses and creeping plants. At the time of our visit (June, 1936) there were two short horns, or spits, running approximately southwards from the eastern and western ends of the cay. These features, on this or any other cay, are but temporary, and will change in appearance and direction following strong winds from various quarters. The cay is formed entirely of sand, and is situated almost at the extreme north-western tip of the reef.

Michaelmas Cay.—There is nothing of any particular interest about this cay; it is larger than that on Arlington Reef, and carries a larger spread of vegetation. But, again, only grasses and creeping plants occur. There is no beach-rock on it, and all the material of which it is



formed consists of fine sand. It rests on the south-western end of the reef, and is elongate in form. The surface is level and flat, descending

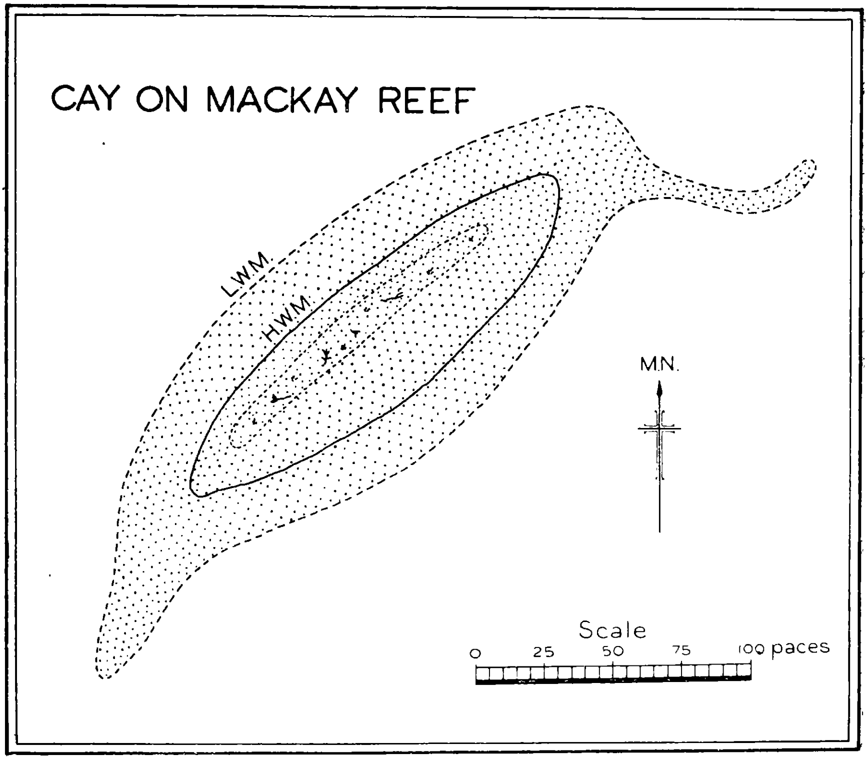


rather steeply in the usual beach-slope. It is the home of countless sea-fowl.

(The simple sand cays are almost exactly similar in structure to the sandy islands of the Bunker and Capricorn Groups. They do, however, stand in rather different environments (see discussion in "Geographical Journal," January and February, 1937).)

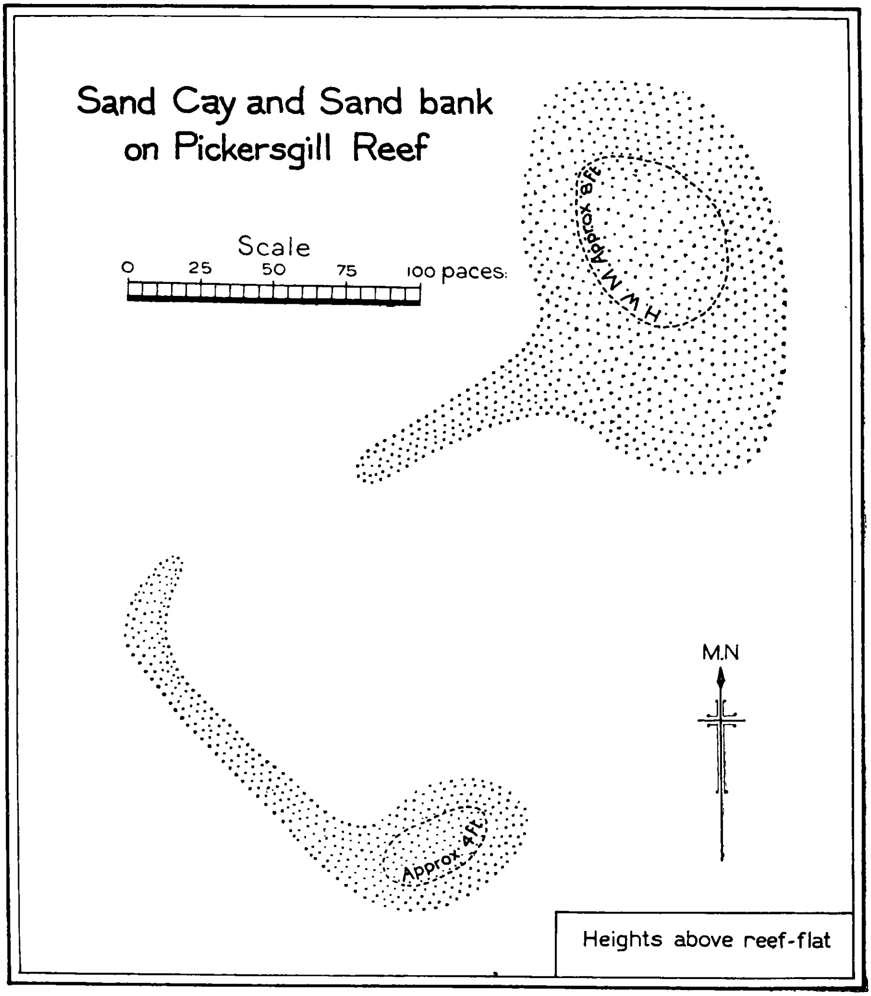
Undine Cay.—Only a rough sketch was made of this cay, but it shows its form sufficiently well. The windward side was the steeper, and the whole island is composed of fine sand. There was no vegetation on it on 11th June, 1936.

Mackay Cay.—This was similarly sketched, and was found to differ considerably from its shape in 1928. The carpet of vegetation



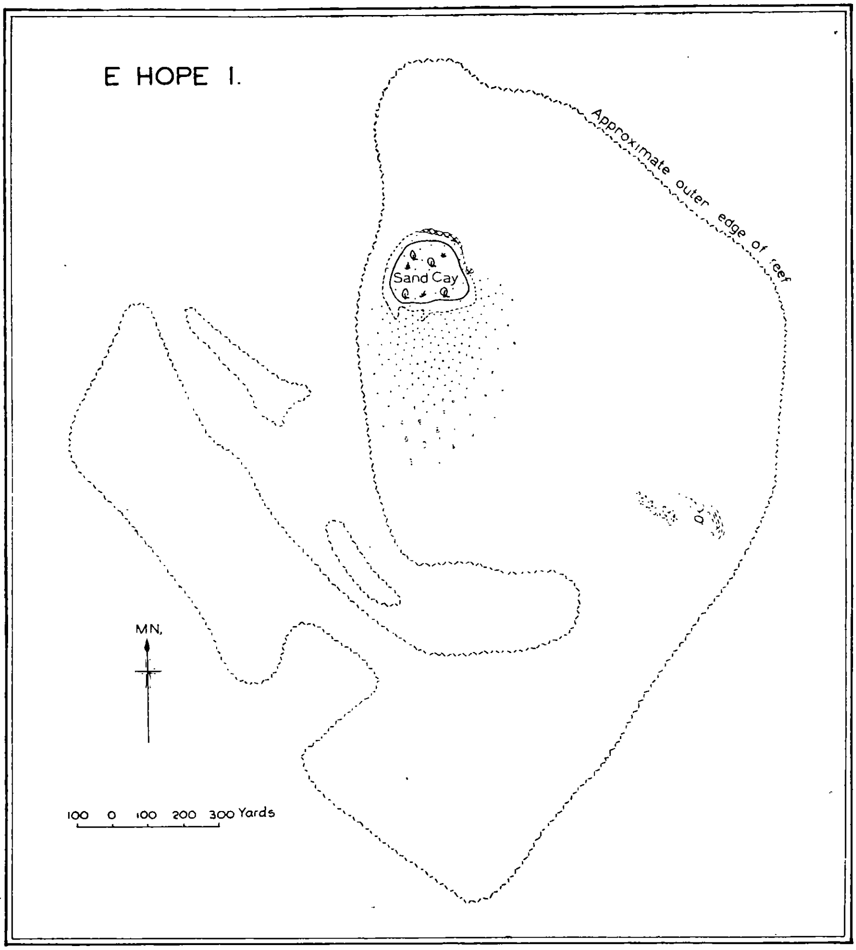
seen in 1928 had disappeared, and in 1936 there were the beginnings of a new cover—*i.e.*, two or three "pieces" of grass, one (?) *Ipomœa*, and a few other plants. All except the grasses were very small. The cyclone in 1934 severely damaged the cay. It is now rather long and narrow, and prolonged into temporary spits. The windward side was the steeper. Both this and Undine Cay showed the usual flat-topped form.

Pickersgill Cay.—Although rather more circular in form, this is similar to those just described. It stands on the lee side of the reef. An independent sandbank, not yet an "island," has formed to the south of it. The reef contains a shallow lagoon. We made several soundings, none greater than 20 feet. There were numerous large coral heads in the lagoon, and in this and other ways it was not unlike that on Lady Musgrave Reef.



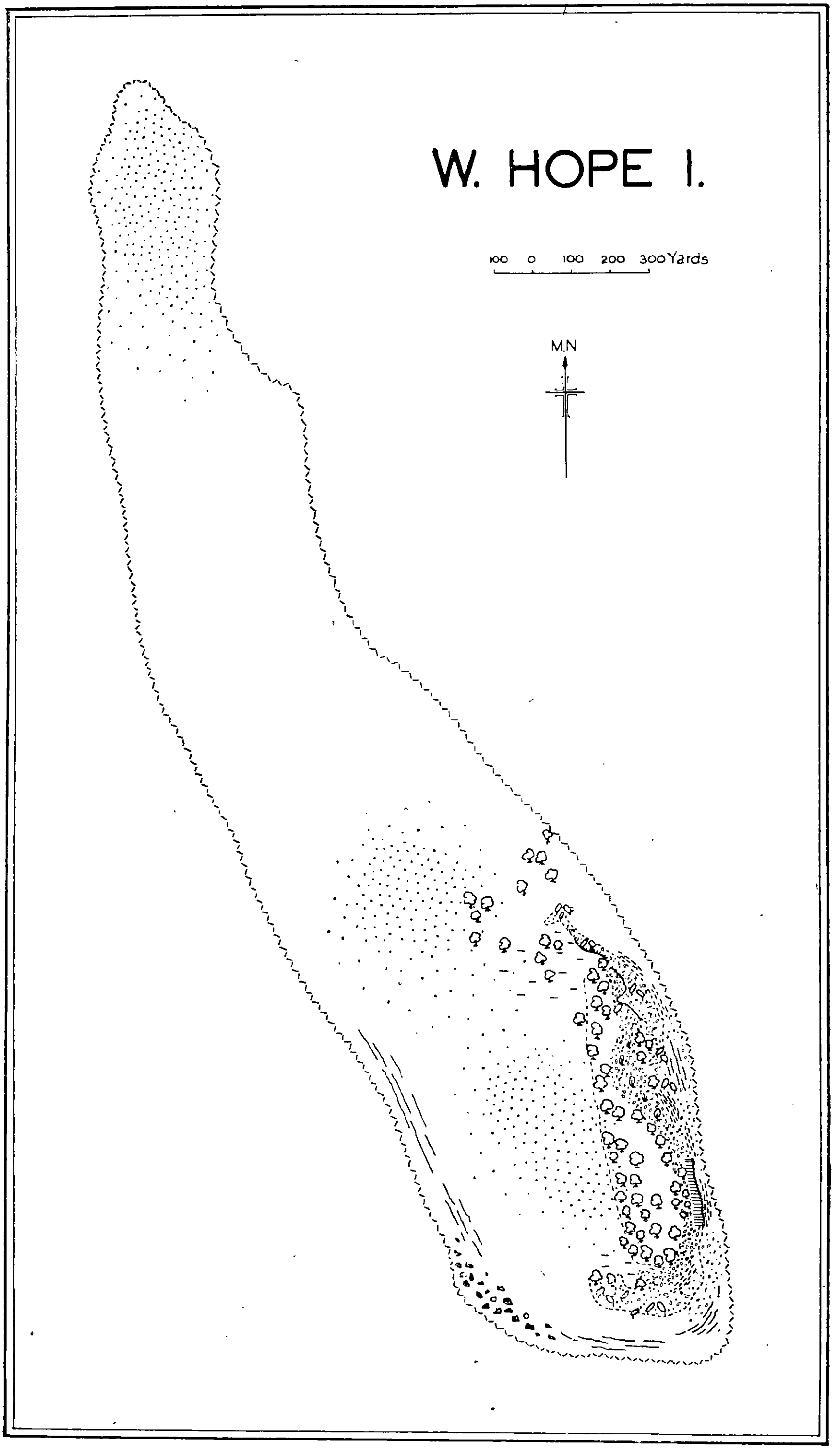
[The islands (with the exceptions of Fife and Pelican Cays) described in the rest of this paper are all low-wooded islands.]

Hope Isles.—The rough outlines of the two reefs on which these islands stand were taken from the Admiralty Charts. The cay on the eastern reef and the mangrove-shingle island on the western reef were traversed in detail. The interesting point about these islands is that the cay and mangrove-shingle island are best developed on separate reefs, but in reality each reef is an entity. On the western reef there was certainly no sand cay, not even a sandbank, in July, 1936. But at the northern end of the reef there was a flat spread of sand in the position indicated on the chart as occupied by a sandbank awash at high water. On the eastern reef, on its windward side, there were some immature shingle banks, with two *Avicennia* trees. Hence, each reef is in one sense a true low-wooded island. The sand cay on the eastern

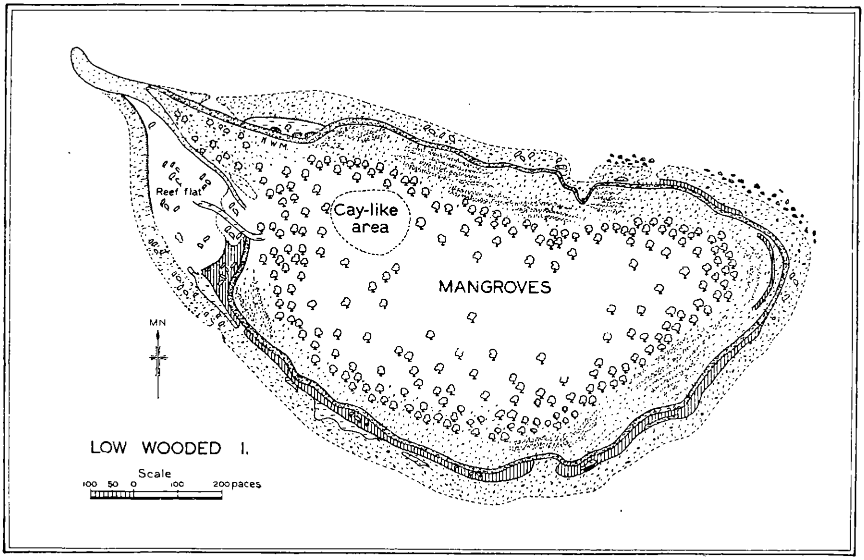


reef is quite normal, and carries a thick cover of vegetation and some beach-rock on its northern side. The mangrove-shingle island on the western reef again shows the features found on this type of island. There is some dry land in the form of major shingle ridges, on which *Pandanus* palms thrive. The lower platform, moat, and basset-edges are all present, as well as a boulder zone to the south-west. The island was traversed by Mr. Kemp, but the writer was unable to visit it.

[Apart from the cay and mangrove-shingle island, the two maps of Hope Reefs are very rough, and serve only to give the most general representation of their features.]


W. HOPE I.
100 0 100 200 300 Yards
M.N

Low-wooded Island.—Although all low-wooded islands have much in common, one type is well exemplified in this particular island. The map was made by means of a careful compass traverse, and shows the significant features. The most striking point is the indefiniteness of the sand cay. A cay-like area certainly exists, and corresponds to the usual arrangement in general position; but it is entirely enclosed by mangroves and shingle ridges. There is also a great deal of pumice on

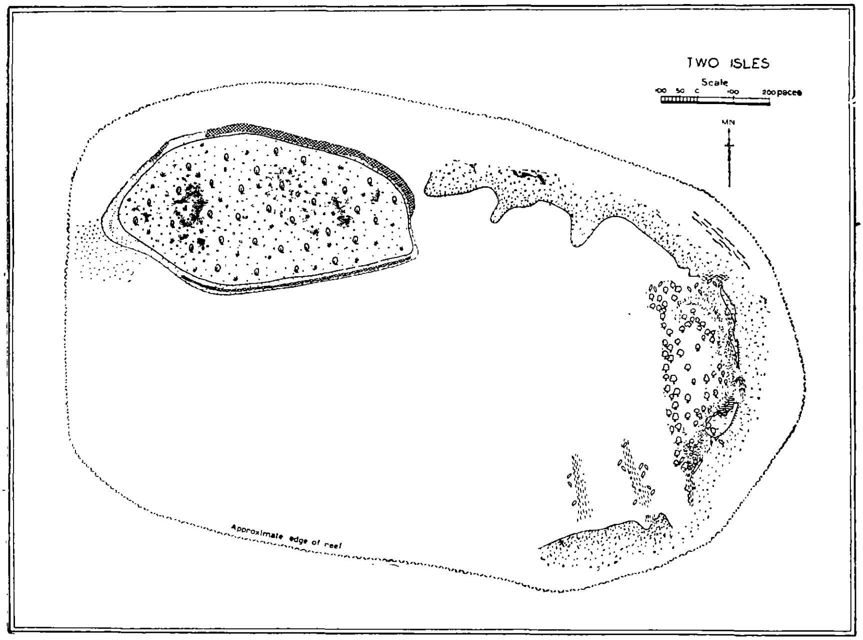


the cay. The cay vegetation closely resembles that of other cays of low-wooded islands. To north-west the cay passes, rather indefinitely, into a sand-and-shingle spit which certainly appears to be the newest part of the whole island structure.

The interior consists almost entirely of mangroves, cut up, as in other cases, by channels and glades.

The outer part of the island was composed of a more or less continuous shingle ridge which, as shown on the map, often enclosed many older ridges; hence, the mangroves were nearly framed by ridges which carried a dry land vegetation. Near the eastern end there are some well-defined and roughly concentric ridges which enclose a low area in which are remains of what appears to be the lower platform, largely covered by *Sesuvium*. Farther to the south-east the shingle ridges are wider and enclose a large lagoon in which are some rock-masses which may be remains of the higher platform. Farther to the south occur some high, old, and well-vegetated shingle ridges. Some of these are, by estimation, nearly 20 feet above the reef-flat. They may conceivably be former hurricane beaches, but, taken into consideration with the lower platform (see below) and allowing for their height and disposition, I strongly suspected they were really raised shingle ridges. This view is supported by the fact that there are also fragments of coral conglomerate platforms within the hollows enclosed by these ridges. Farther to south and south-west the same features occur, but the ridges are not so high. They are covered by a land flora, but in this part of the island they do not suggest any change of sea-level.

Outside the enclosing shingle ridges the lower platform is magnificently developed, and along the southern shore is continuous and very promenade-like for long distances. Where it does not exist, or has been eroded away, the shingle ridge has been pushed further back (see, *e.g.*, near the farthest south point on the map). *Avicennia* and *Sesuvium*



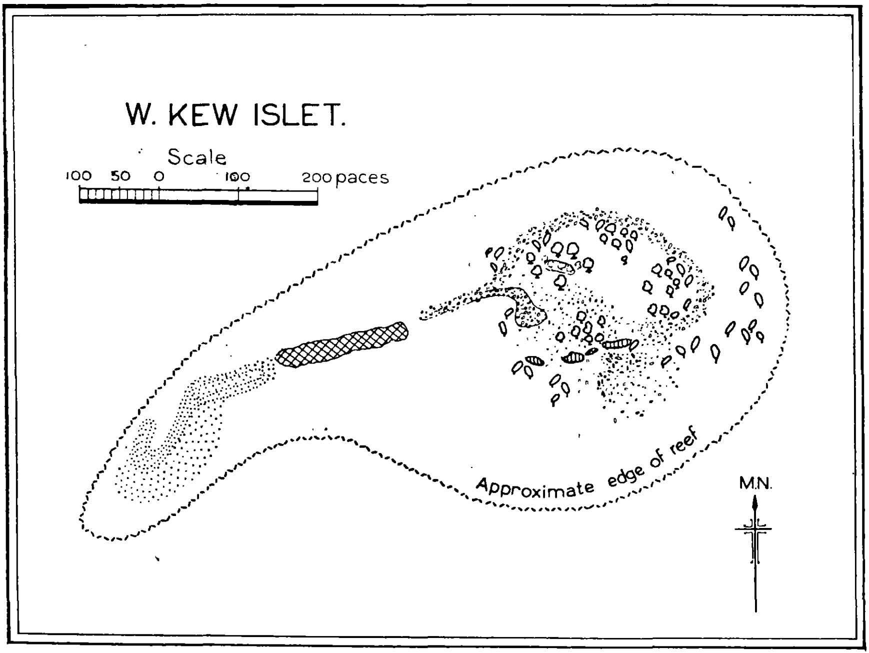
grow over much of the platform. There is a boulder zone to the north-east, and along the northern shore are isolated patches which appear to be remnants of a former and more continuous platform. On the windward side of the island there are rather low, but distinct, outer ramparts and an incipient moat.

The whole structure is thus more confused than in the majority of this type of island. All the expected features are found, but there is far less clear differentiation between them. The island, in this way, stands in marked contrast to its nearest neighbours—Three Isles and Two Isles. It would be interesting to have this island mapped as carefully as Spender was able to map Three Isles.

Two Isles.—The sand cay on this reef is probably the finest we visited (*i.e.*, of the low-wooded islands). It is well developed, and built up to a greater height than usual. On the sheltered side and within the vegetation is luxuriant; the trees are high and well grown. On the weather side the vegetation is more open, with a large number of *Pandanus* palms. The cay is fringed by beach-rock on its northern and southern sides—that to the north and north-east being wider and higher. There is, however, nothing to suggest any recent alteration in sea-level. The reef flat practically dries at low-water springs.

The mangrove-shingle island is somewhat disappointing. Shingle ridges are prominent, and, as shown on the map, fairly continuous, so that a true island occurs. There are also basset-edges and a very fragmentary lower platform. The mangroves cover a rather restricted area. South-west from the main mass of mangroves some small "islands" are to be seen. These are probably developing, but the features are by no means definite. They were fringed by some basset-edges which were practically level with the present ramparts. As far as this island is concerned, it appears that ramparts can evolve into basset-edges without any change of sea-level. In this, and other ways, the island rather resembles Low Isles. We were less convinced here than on any other island visited that the lower platform is a raised feature. This is an interesting point because Two Isles, Three Isles, and Low Wooded Island are close neighbours, and while each shows similar features, at the same time each one emphasised those features in a different way. They are not very far from Cooktown, and if a physiographer and a surveyor could spend even a week or two on these islands and map them in more detail some very interesting comparisons should result. The present map was made as a compass traverse—the general outline of the reef enlarged from the chart and roughly checked on the "ground." The extension of the outer rampart along the northern side of the reef towards the sand cay is worth noting, and may be compared with the somewhat similar feature on Low Isles.

Western Kew Islet.—Although this is but a small island on a small reef, it offers several points of interest. On the northern and north-eastern sides there are no traces of a platform, but the reef-flat is very rough, and there is a well-defined inner rampart which, in places, is encroaching into the mangroves. Roughly, at its eastern apex this rampart encloses a deep hollow into which mangroves are spreading. *Avicennia* occurs on the east of the reef-flat. Farther to the south-east and south there are fragments of the lower platform. These are very broken and eroded on their outer side. Inside the main mass of mangroves there was a small lagoon with traces of the lower platform around it. There is a definite but small shingle island, best developed on the western side of the mangroves. It consisted of several more or less distinct ridges. Running westwards from the mangroves was a relatively long and conspicuous ridge of shingle. This terminated rather abruptly, and after a short break the same general line was continued by a remarkable mass of beach-rock and beach-conglomerate, the top of which averaged about 4 feet above the reef-flat. The strike was about 70° (magnetic), and the dip a little to the west of north. It is now quite isolated, but when it was formed it presumably partly surrounded a former cay, no trace of which remains. Beyond this again was a sand-bank, consisting of coarse sand and fine shingle, awash at high water.

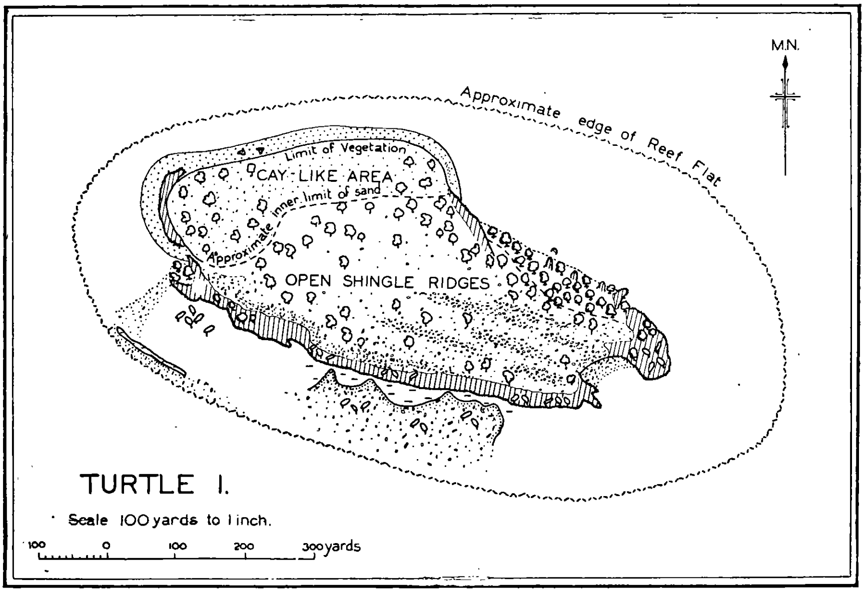


It corresponded exactly to the true sand cay seen on so many of this type of island. There was no beach-rock around this bank.

Turtle 1 Island.—Although several days, largely on account of very bad weather, were spent in the Turtle group, only one island was mapped in detail. Notes on three others were published in the paper already referred to in the *Geographical Journal,* February, 1937.

This particular island is interesting, because there is no clear break between the cay and the mangrove-shingle island. The part marked ''cay-like area'' is sandy and resembles the ordinary cay in all respects. But it had an ''old'' aspect, and the sand had often passed into a brownish ''soil.'' The shingle ridges run right up to it, except on the south-west, where a channel separates them from it.

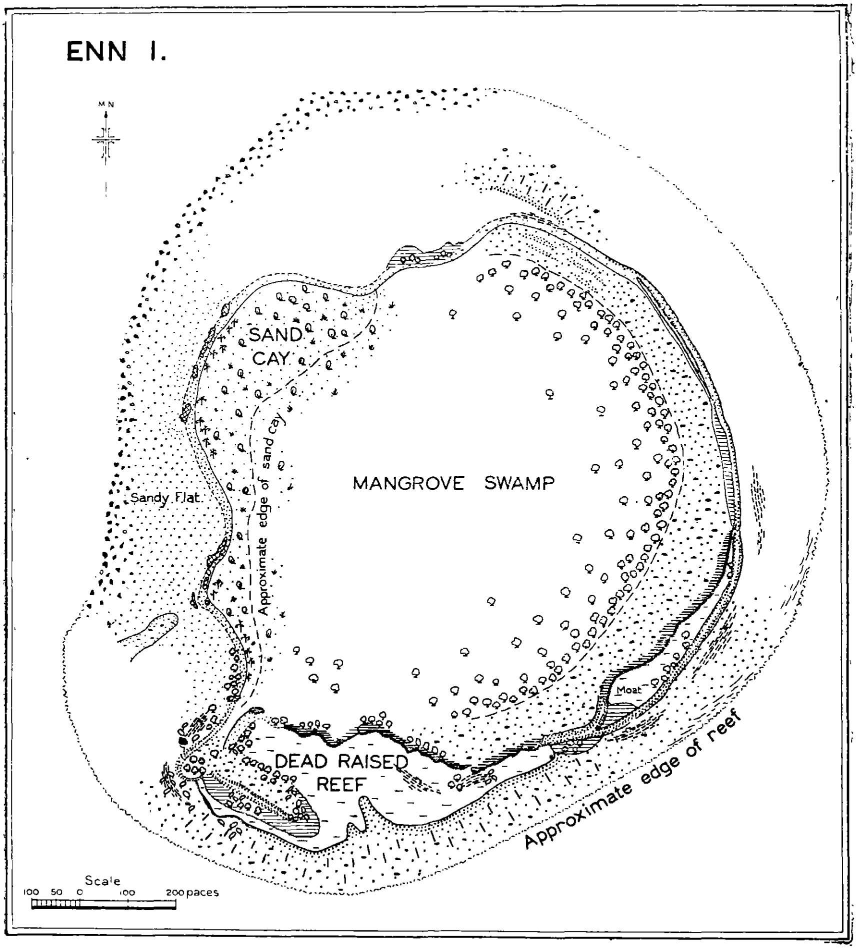
By far the larger part of the island consist of shingle arranged in ridges running generally in the direction shown on the map. The interior of the island is rather open, and the ridges are mostly covered with grass and creeping plants. Trees enclose this open part on all sides. The lower (conglomerate) platform is well developed, especially to windward. It stands about 3 feet above the reef-flat, and its upper surface is often promenade-like. The outer edge is much eroded. Mangroves fringe most of the eastern side of the island, and there are also patches elsewhere. But the mangrove belt is by no means so fully expanded as on most low-wooded islands. *Avicennia* is present on the inner part of the reef-flat and the platform, where also *Sesuvium* is locally abundant. *Suriana* occurs frequently on the inner edge of the platform. On the weather side ramparts and a moat occur.



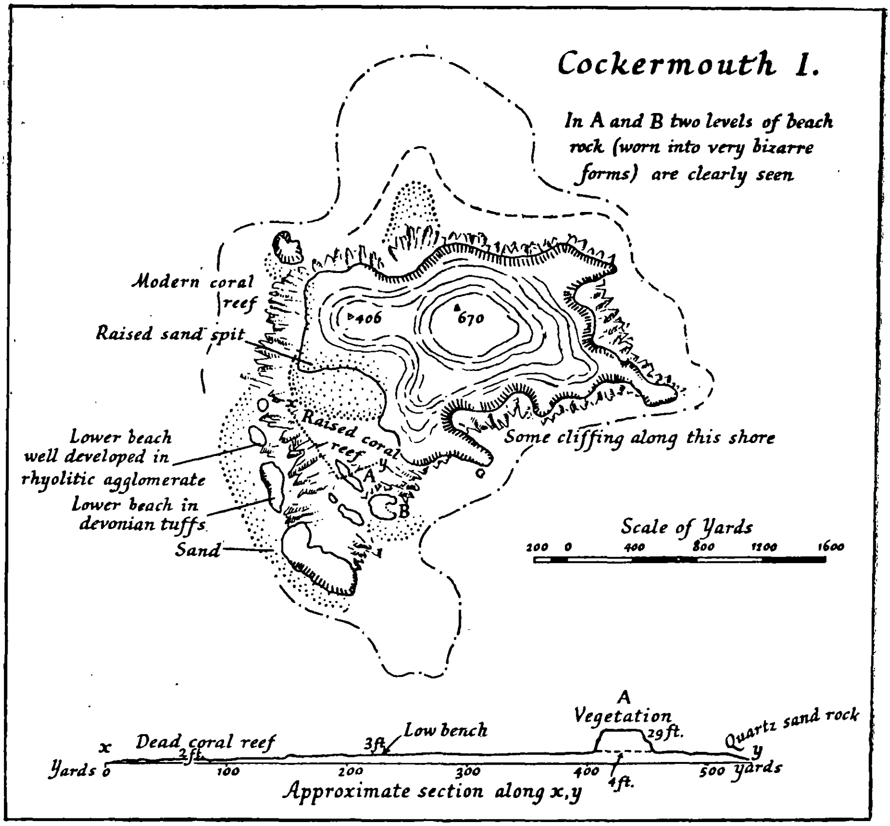
The inner shingle ridges often stand high, and appear to be consistent with the lower platform having been raised relative to present sea-level. Modern, and white, but rather lower shingle ridges are also seen fringing the inner edge of the platform. But *Avicennia, Sesuvium,* and other plants grow on the platform in front of these ridges. Our visit coincided with a moderate to strong south-easterly gale, but it was clear that the vegetation on the platform had not been disturbed, even in exposed places. The low inner and new shingle ridge may result from a special storm; there is, I think, no need to conclude that the higher and inner ridges were similarly formed. As suggested above, it seems to be more consistent to relate them to an earlier time before the platform was raised. Fragments of old platforms are often found inside the mangroves. In some ways the island resembles Low Wooded Island. It was carefully surveyed by a plane-table and chain traverse.

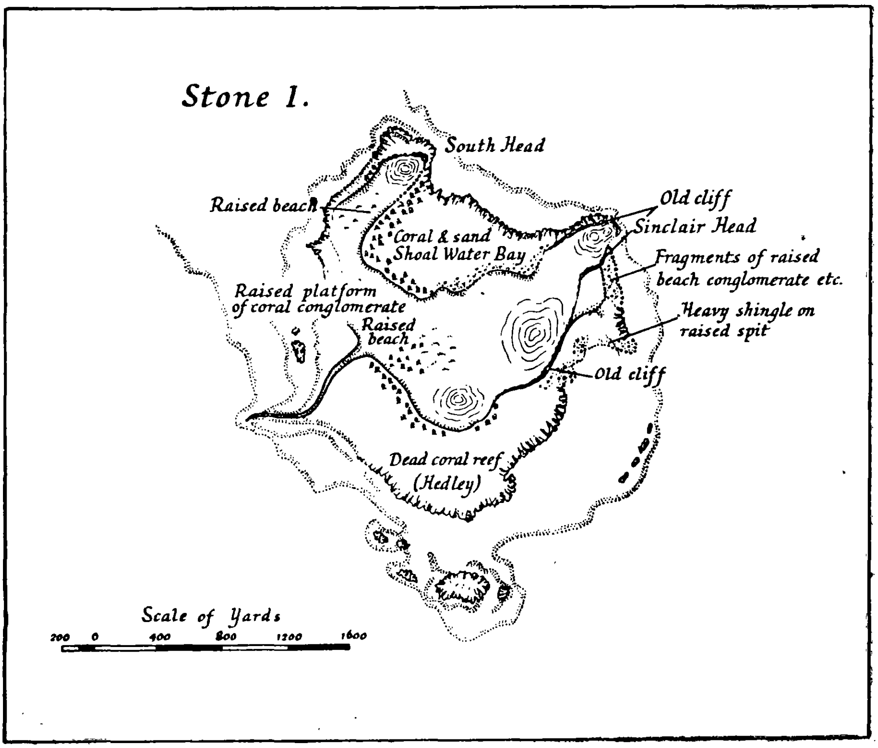
Enn (= *N*) *Island.*—The features characteristic of low-wooded islands were remarkably well seen on this island, which stands in a fairly isolated position. The sand cay is rather irregular in shape, and is not very clearly defined on its eastern side; but it shows all the usual features. There are fragments of beach-rock along its western side, and some of the rock stands high and *may* be associated with the higher platform, but this is doubtful. Dense vegetation on the inner side of the cay makes it difficult to map its edge decisively.

The weather and southern sides are by far the most interesting. To the north-west there is the usual boulder zone, which, incidentally, also fringes a large part of the western side of the reef. But inside the north-eastern and weather sides there is a high and continuous inner rampart, enclosing, in parts, a low-lying area sometimes containing a lagoon. For the most part the inner rampart is merely the outer edge



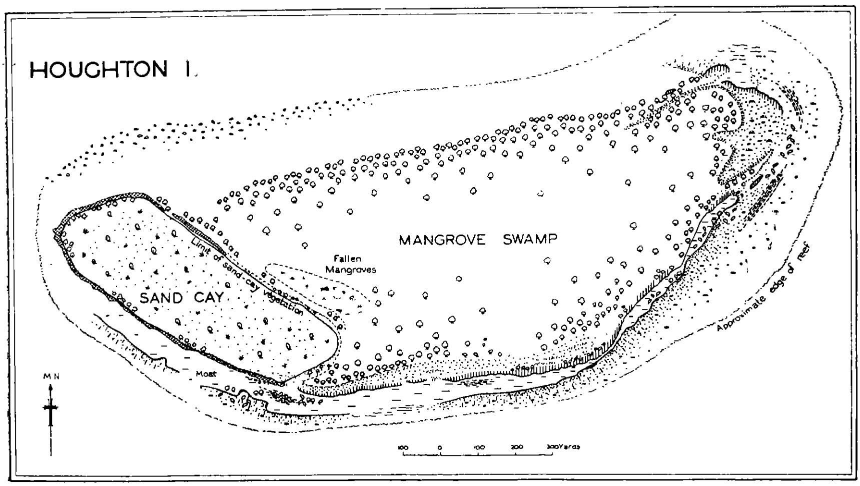
of a broad zone of shingle ridges which make a true shingle island. This was the largest of the true shingle islands we visited. The vegetation on the shingle is "open," and the whole aspect was rather dreary and arid. Occasionally there is water just within the newest inner rampart, and in such places a good development of the higher platform occurs and appears to run under the older shingle ridges. This is best seen along the eastern part of the island, where the word " Moat " is printed inside the inner rampart. At the southern end of this moat the lower platform runs back to the higher one, and a difference of level between the two of approximately 3 feet is seen.


Cockermouth I.
In A and B two levels of beach rock (worn into very bizarre forms) are clearly seen
Modern coral reef
Raised sand spit
406
670
Raised coral reef
Lower beach well developed in rhyolitic agglomerate
Lower beach in devonian tuffs
Sand
A
B
x
y
Some cliffing along this shore
Scale of Yards
200 0 400 800 1200 1600
A
Vegetation
Dead coral reef
2ft.
3ft.
Low bench
29ft.
Quartz sand rock
Yards 0 100 200 300 400 500 yards
4ft.
Approximate section along x,y


Stone I.
South Head
Raised beach
Coral & sand Shoal Water Bay
Old cliff
Sinclair Head
Fragments of raised beach conglomerate etc.
Raised platform of coral conglomerate
Raised beach
Heavy shingle on raised spit
Old cliff
Dead coral reef (Hedley)
Scale of Yards
200 0 400 800 1200 1600

On the southern side of the mangrove swamp the higher platform reaches the "foreshore," and stands, an an average, 7 feet above the reef-flat. It is also in this part of the periphery that the true outer rampart is best seen. The higher platform is suffering considerably from erosion, and is often undercut to 10 or more feet. In other places a bench is being cut in it at about the level of the reef-flat. As shown on the map, much of this part of the complex is formed of an ancient reef, now raised. This reef corresponds very well with similar reefs seen on Holbourne Island and Stone Island. (See *Geographical Journal,* January and February, 1937). Some of the former reef can be seen exposed beneath the upper platform where it has been undercut.

At the northern end of the shingle island the ridges gradually die out, and, as shown, turn so as to run towards the northern end



of the sand cay. At the extreme south-western end there is a small shingle "peninsula," around which the lower platform is found. Here and elsewhere basset-edges are seen. The mangrove area is much enclosed and not easy to penetrate.

Enn Island is, then, of more than usual interest; it is compact, has well-developed sand and shingle islands, and shows the upper and lower platforms more clearly than elsewhere. It may be useful to regard it a standard of reference.

Houghton Island.—The three islands—Howick, Houghton, and Coquet—really form a distinct group, together with a few smaller reefs. Howick differs from the others because it is partly formed of granite. But Houghton Island shows to a marked degree the features of a low-wooded island. It stands on and nearly covers a reef elongated roughly east and west.

The sand cay is, perhaps, the most interesting of its features. It is large, well-developed, and extremely clearly defined. It is almost entirely composed of sand, though there is some scattered shingle near the mangroves. It is fringed by beach-rock along nearly three-quarters of its periphery. Some of this rock stands about 7 feet above the reef-flat, and almost certainly represents the higher platform. It is well worth noting that in places on the western side of the cay the sea at high water is cutting into this rock and forming a platform approximately at or little above reef-level. The top of the platform is often level, but its seaward edge is steep and undergoing erosion. Towards the north-western end of the cay some excellent "unconformities" are seen in the beach-rock.

The southern side of the mangroves is fringed by the lower platform almost continuously. It is a little irregular in height, but lower than the platform just described round the western side of the cay. Sometimes this lower platform lies behind shingle ridges, and so lagoons or moats are held between it and the outer rampart. It is often very jagged.

At the eastern end of the mangroves a small shingle island is found. It is built of individual shingle ridges which run into the mangroves. Traces of the lower platform are also found to windward of the shingle cay. The map shows that outer ramparts, moats, and basset-edges all occur in the normal positions. On the northern side of the reef the mangroves are not fringed by any shingle, but their outer edge on the reef-flat is well defined. The boulder zone is best developed to the north-west. Parts of the mangrove area have not yet recovered from a cyclone, so that there are "devastated" areas. The beach-rock on the side of the cay facing the mangroves does not afford any evidence of change of level.

Bewick Island.—Apart from the higher platform, this island shows the characteristic features of low-wooded islands with great clarity. The sand cay is large, well-defined, and well-developed. It is formed entirely of sand, and is mainly covered with grass, with a few trees and bushes. On its western and northern sides it is fringed by beach-rock which, I think, shows evidence of elevation corresponding with the lower platform.

The mangrove swamp is extensive, and where not enclosed by the cay or windward shingle ridges extends directly on to the reef-flat.

The windward and parts of the north-western sides of the complex are bordered by shingle ridges which really make a series of small islands. As indicated on the map, these islands are usually long and narrow, and their height and general nature suggest that they might be formed under existing conditions. On the other hand, some ridges certainly occur on the lower platform. Granting that hurricanes could easily throw shingle up on to this platform and so form islands, I am still inclined to think that some are probably contemporaneous with the lower platform before, in the writer's view, it was raised.

Along considerable parts of the weather side of the reef the general sequence of features, working inwards, is as follows:—

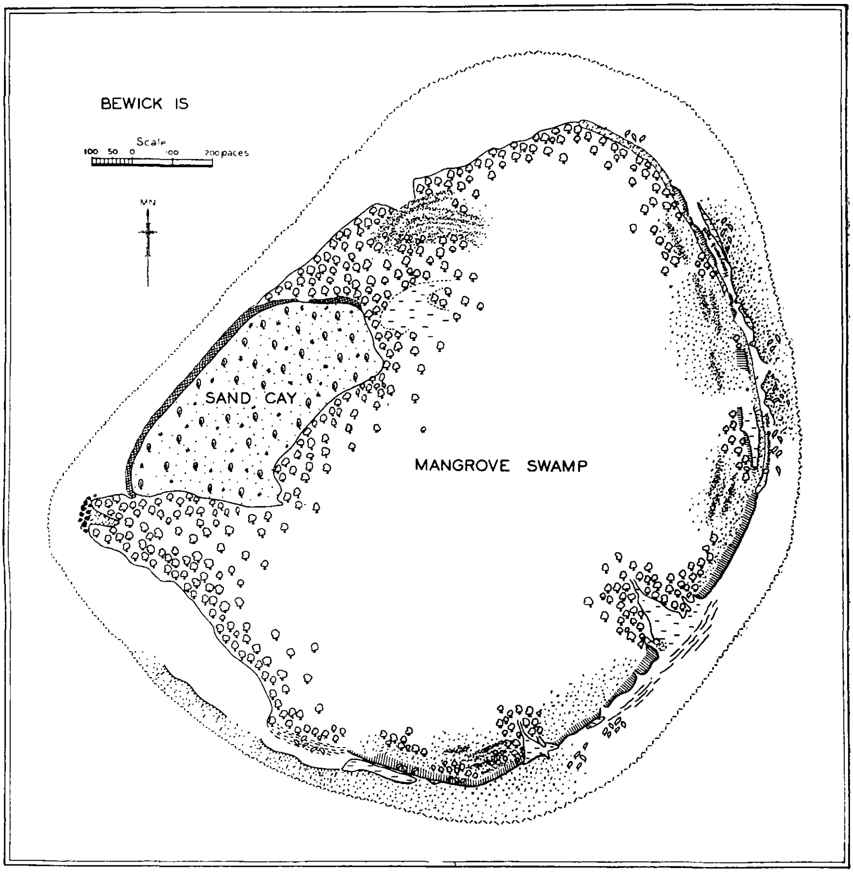
(*a*) The reef-flat and algal ridges;

(*b*) Outer shingle ridges or ramparts;

(*c*) Moat;

(*d*) Lower platform, often much eroded, and, in places, represented by basset-edges;

(*e*) Inner ramparts, which are usually (not always) merely the outer ridges of a true shingle island.

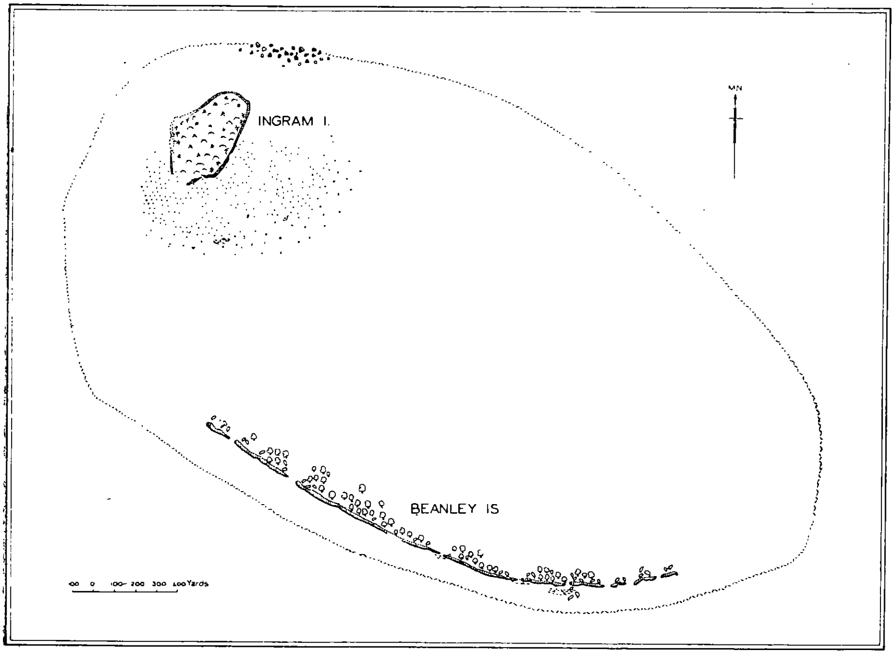


Occasionally along the windward side a narrow low, with mangroves, occurs inside the lower platform and associated shingle ridges, to be bordered again on its inner side by an older fragment of platform. Progradation in this way would appear to be a normal process.

The boulder zone is not very conspicuous; the most obvious part of it is a small mass to the south-west of the sand cay.

B

Ingram and Beanley Islands.—Different names for the sand cay and the mangrove-shingle island are unusual, but in this case not unjustified. The reef is large, and Ingram Island (the sand cay) is some distance away, and absolutely distinct, from the mangrove-shingle (Beanley) Island.



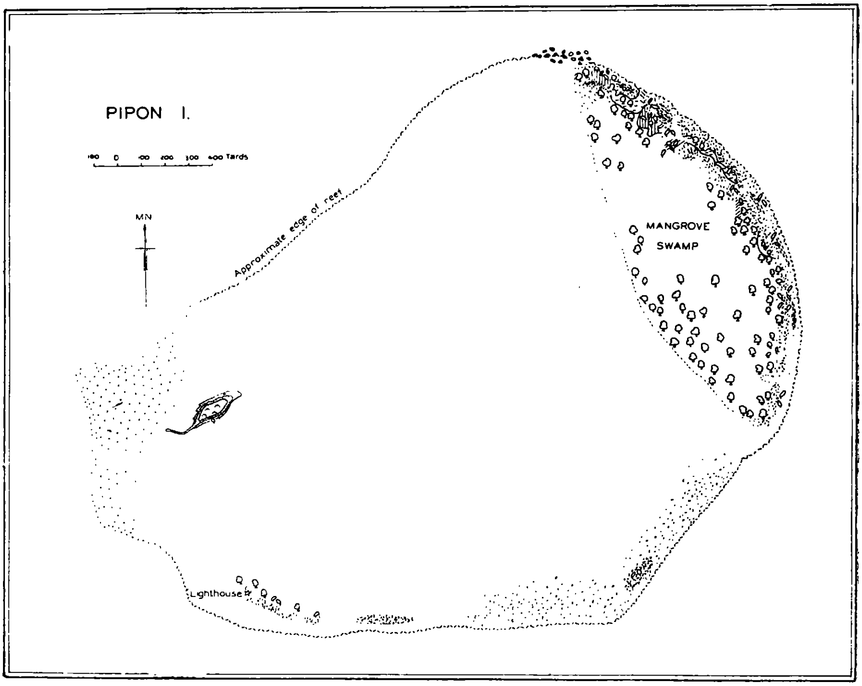
The cay is normal, well-developed, and stands high. Much of its height results directly from blown sand which can to some extent come off the extremely sandy reef-flat at low water. On the other hand it is certainly possible that the sandy surface of this reef was caused by the destruction, through a cyclone, of a former cay. The present cay is nearly surrounded by beach-rock, and in two places—one to the north and north-east, the other to the south-west—the beach-rock is at a considerable height above the reef-flat. We felt that both these represented traces of the higher platform, but it is pertinent also to say that on the northern side of the cay large masses of lower beach-rock had been torn off in a hurricane and thrown well up the side of the cay.

A small boulder zone existed on the north-west of the reef.

Beanley Island is a curious structure. The lower platform is remarkably well developed, but, especially at the eastern end, it is often intersected by deep gaps. The upper surface is promenade-like; the outer edge jagged and eroded. The flat in front of it is practically devoid of true ramparts and moats, though occasional incipient traces of them were seen. However, as ordinarily understood, they are absent.

There was also a marked absence of sand and shingle in ridge form inside the platform. In fact, the platform, which was sometimes grassed over, was the only significant feature apart from algal terraces which were prominent in its gaps. The mangrove area was but poorly developed and narrow.

In some ways, the whole complex was not unlike Pipon Island, but, whilst conforming to the general pattern of low-wooded islands, it really formed an entity differing considerably from any other we visited.



Pipon Island.—The reef on which this island rests is a large one, and is much covered in its central part by *Thalassia.*

The sand cay is small, but occurs in the normal position. It is almost surrounded by beach-rock which certainly does not correspond precisely to the present island, because it is not in conformity with the slope of the beach. The rock is sometimes horizontal, but its dip varies a good deal. Its upper surface is generally level, and there seems little doubt that it is all part of the lower platform. It is awash at high water. The cay is high and built up partly around bushes by blown sand. The former lightkeepers' houses stood here, and as their foundations still remain, the cay is hardly normal, because these foundations have also helped to collect the sand.

The present automatic light stands on a small shingle "island" on the south-western edge of the reef. It is doubtful if any of this "island" would be uncovered during a high spring tide. It is, however, an embryonic island, and in course of time should become larger and higher. *Avicennia, Sesuvium,* and *Rhizophora* are all present on it in their normal positions.

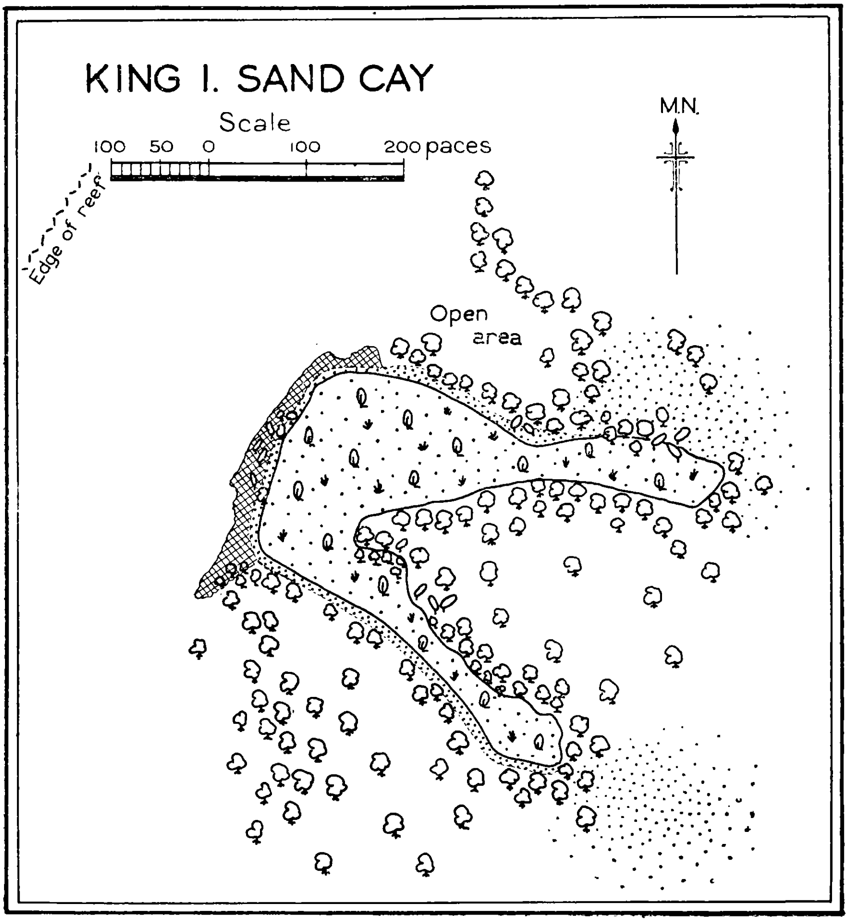
Similar partly-grown islands are also found between the lighthouse and the true mangrove-shingle island. The latter conforms to the usual pattern. The reef-flat, with many algal terraces, is bordered on its inner side by a fragmentary outer rampart and a discontinuous moat. There are also traces of the lower platform. The inner shingle ridges are better developed, and often form small but true islands. Occasionally the platform reappears inside the ridges.

The mangroves on their exposed side are wind-swept, and although the reef is situated in a windy region (just off Cape Melville), the fetch of the waves is not great. Various modifications may result from these facts, and may explain why the mangrove-shingle complex differs slightly from other islands. The mangroves are gradually spreading towards the cay, but the general appearance is unlike that of many islands we visited, and is somewhat reminiscent of Low Isles. To the south and south-east of the mangroves there are marked algal terraces and a low but typical outer rampart. The boulder zone is again best developed at the north-western end of the main mangrove island; boulders also run farther towards the cay than shown on the map. There are only a few scattered boulders on the reef-flat.

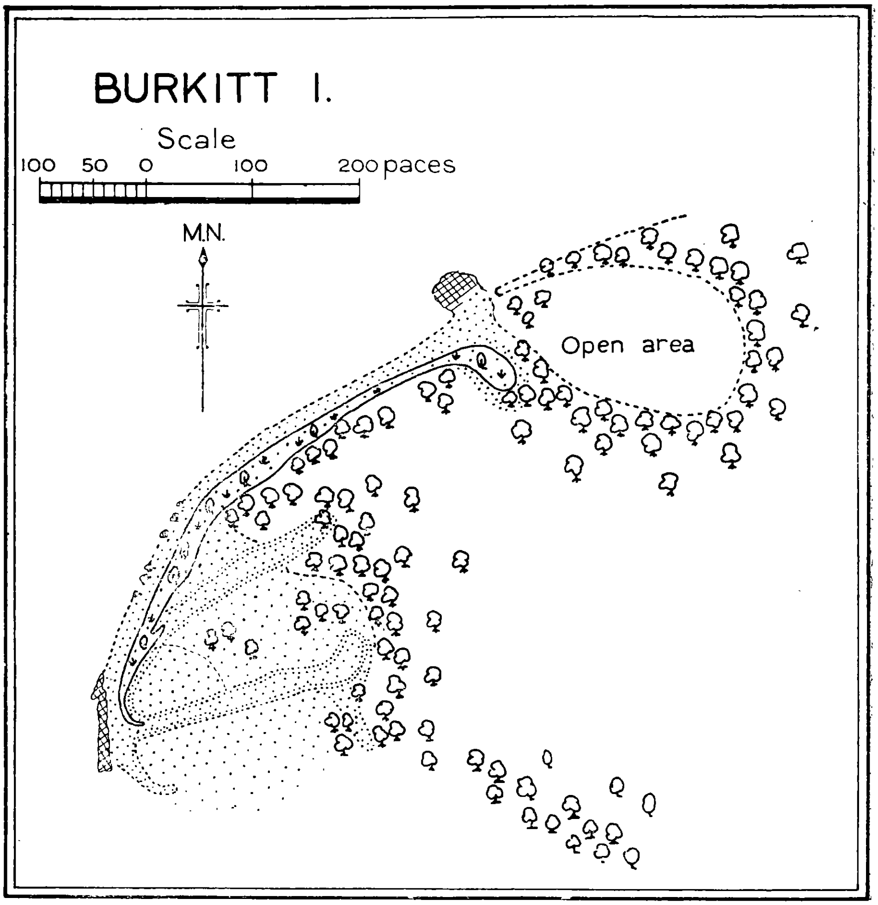
King Island.—The sand cay only was mapped on this island. It is interesting because of its irregular shape. It consists of a nucleus with two long horns running east and south-east into the mangroves. It is made entirely of sand, and is in every way, except in its shape, quite normal. Beach-rock is well-developed on the western side, and its level and general nature suggest that it corresponds with the lower platform. The outer edge is much eroded, and its surface is partly covered by *Sesuvium* and *Avicennia.*

The boulder zone is again best seen to north and north-west of the reef. Cay and mangroves are generally clearly defined, and, as on so many other reefs, the mangroves are gradually spreading over the lee side of the reef-flat.

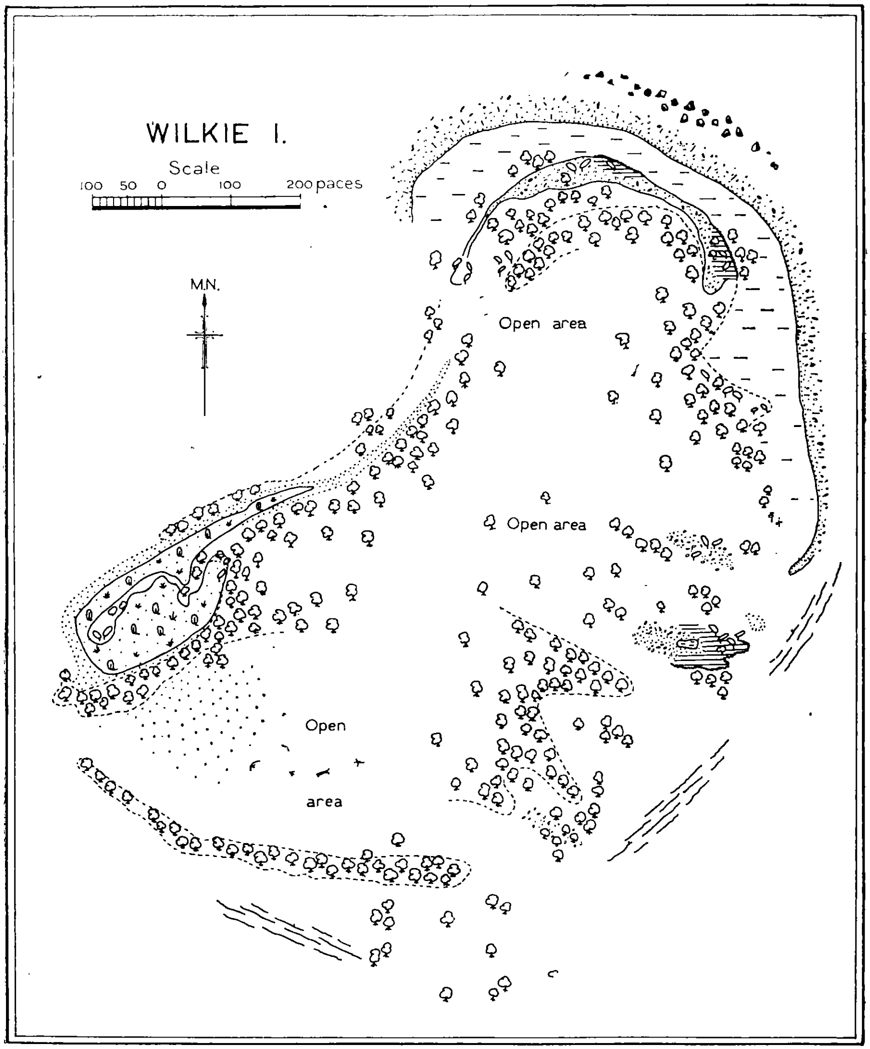
The following notes refer mainly to the weather side of the island:—Starting at the north-western end of the shingle area, there is first a series of shingle ridges, often quite high. The lower platform, moat, and outer rampart soon begin. In one place there is the unusual feature of *seaward*-dipping basset-edges of coral-conglomerate. This appeared to result from the erosion of a former recurved and lithified shingle ridge, so that near the recurved end basset-edges could strike in various directions. Modern, white shingle ridges are usually found on and inside the lower platform, and drop down into the mangroves. The main mass of the weather side of the island is quite normal. There are several masses of shingle ridges forming true shingle islands. The material of which they are formed is usually coarse. The moat is generally narrow, but towards the south-east the shingle ridges become higher and broader, occasionally enclosing lows between them. *Rhizophora* often grows in these lows. Farther to the south the inner shingle ridges become narrower, and the main mangrove area is just within them. At the same time the outer rampart begins to break down. Some of the inner shingle ridges stand sufficiently high, and suggest that they were formed before the movement occurred which the writer thinks brought the lower platform into being. *Suriana* growing on the rather worn and old-looking platform also suggests this same movement. An inner platform often occurs, and carries high-standing shingle ridges. Although it was not levelled, both Mr. Kemp and the writer considered that the inner platform was rather higher than the outer one, but we did not think it represented any different level of the sea.



Burkitt Island.—Here, again, only the sand cay was mapped. It somewhat resembles King Island cay because it is formed of several major sand ridges. The lows between these ridges contain mangroves and shallow lagoons. It stands in the usual place on the reef, and differs from others mainly by reason of its shape. There is but little beach-rock on it.

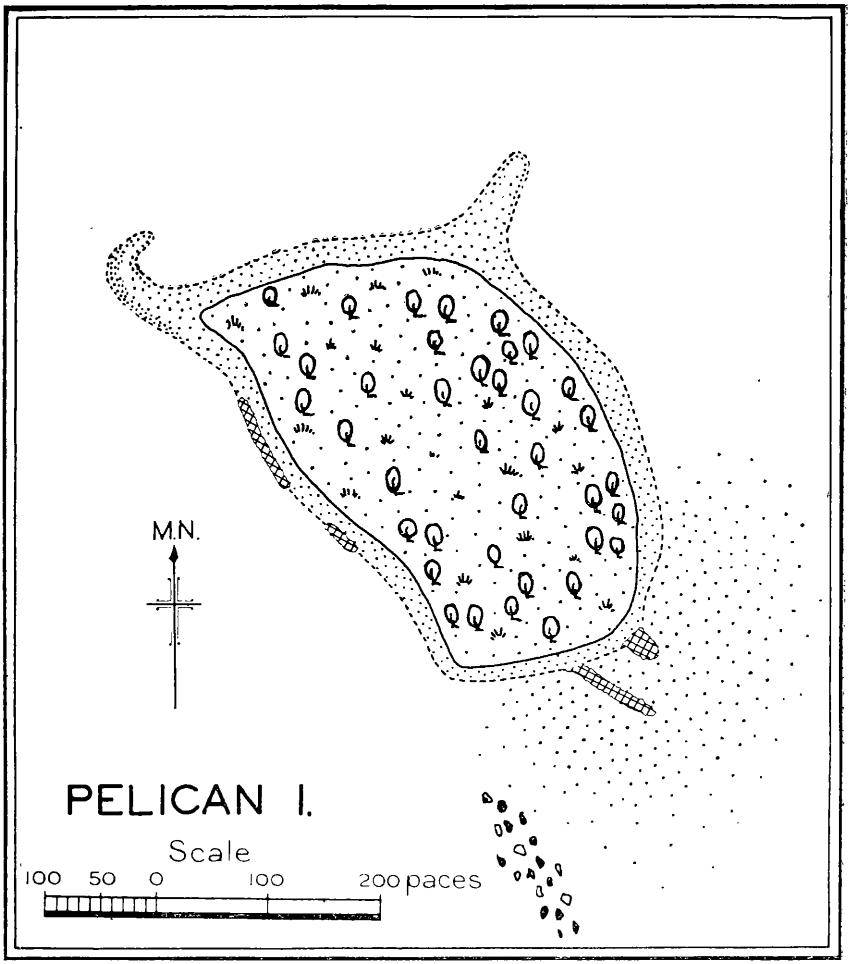


The weather side of the island shows several features of interest. To the north the shingle ends in a high modern ridge and "knot," rather reminiscent of that at Low Isles. No true moat was present on this part of the reef. Farther eastwards an outer rampart begins. At first it encloses a flattish area with basset-edges, and a little farther on an inner rampart. The moat is well seen, and to the east coincides with a belt of well-defined basset-edges. Shingle ridges occur on both inner and outer sides of the moat. The lower platform is best seen still farther to the east and south-east. The moat gradually becomes less clear, and the platform is interrupted by wide breaks. Near the south-east the mangroves are by no means so thick as in the corresponding parts of other low-wooded islands. On the south-western part of the reef the mangroves spread out in "park-formation." There are occasional traces of an outer rampart to the south of the reef.

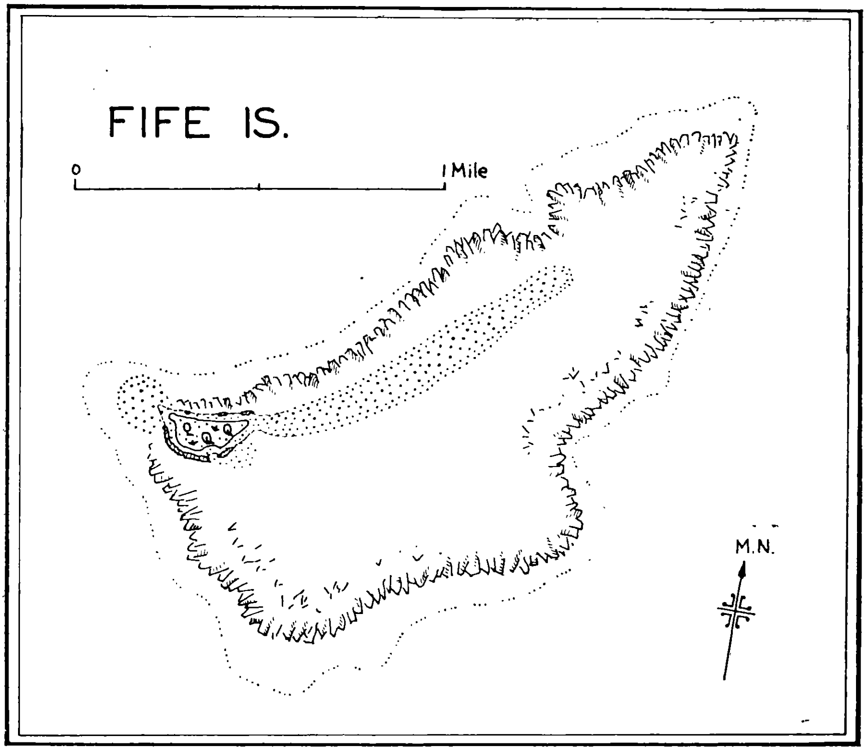


In one place, in particular, the platform can be seen to break down into basset-edges. Here, too, the slope and cross-section of the platform are almost the exact counterpart of a wide, well-developed outer rampart which has been lithified. The basset-edges begin as slight depressions in the lower part of the front slope of the platform. This example was carefully studied, and the view that the platform develops (through lithification, slight uplift, and erosion of its outer edge) from an outer rampart seemed quite conclusive. Usually only the higher and flatter parts of platforms now remain, and because of the erosion they have all suffered on their seaward faces their original rampart-like cross-section is obscured.

Wilkie Island.—The sand cay is normal in position, but contains one or two hollows in which mangroves are growing. New sand ridges



appear to have been added to a nucleus in such a way as to form these hollows. The cay is clearly differentiated from the mangrove swamp proper. A long shingle ridge runs north-eastwards from the cay and inside the outermost mangroves. The mangroves over large parts of the reef grow on a sandy surface. The whole place had been devastated by a cyclone, and was extremely depressing. It is probable that much of the sand on the reef-flat had been distributed (from the original cay?) in this way. The shingle bank running from the cay also rims the north and north-east of the reef, and is interrupted by "knots" of shingle which, by their nature and disposition, suggested that various discrete and peripheral banks had been forced together as a result of wave action. Fragments of the lower platform ran outside the ridges. These fragments are all extremely rough, and their upper surfaces consist almost entirely of basset-edges. The moat and outer rampart are the best features of the whole complex; they are, in places, magnificently developed. The outer rampart (see map) is continuous over long distances, and fine algal terraces are found in its occasional breaks and elsewhere. The southern half of the complex is far less



definitive. There is little or no shingle, and the mangroves grow in clumps. Our visit to this island corresponded with awkward tides, so that traversing was extremely difficult. The map, however, shows the chief features quite clearly.

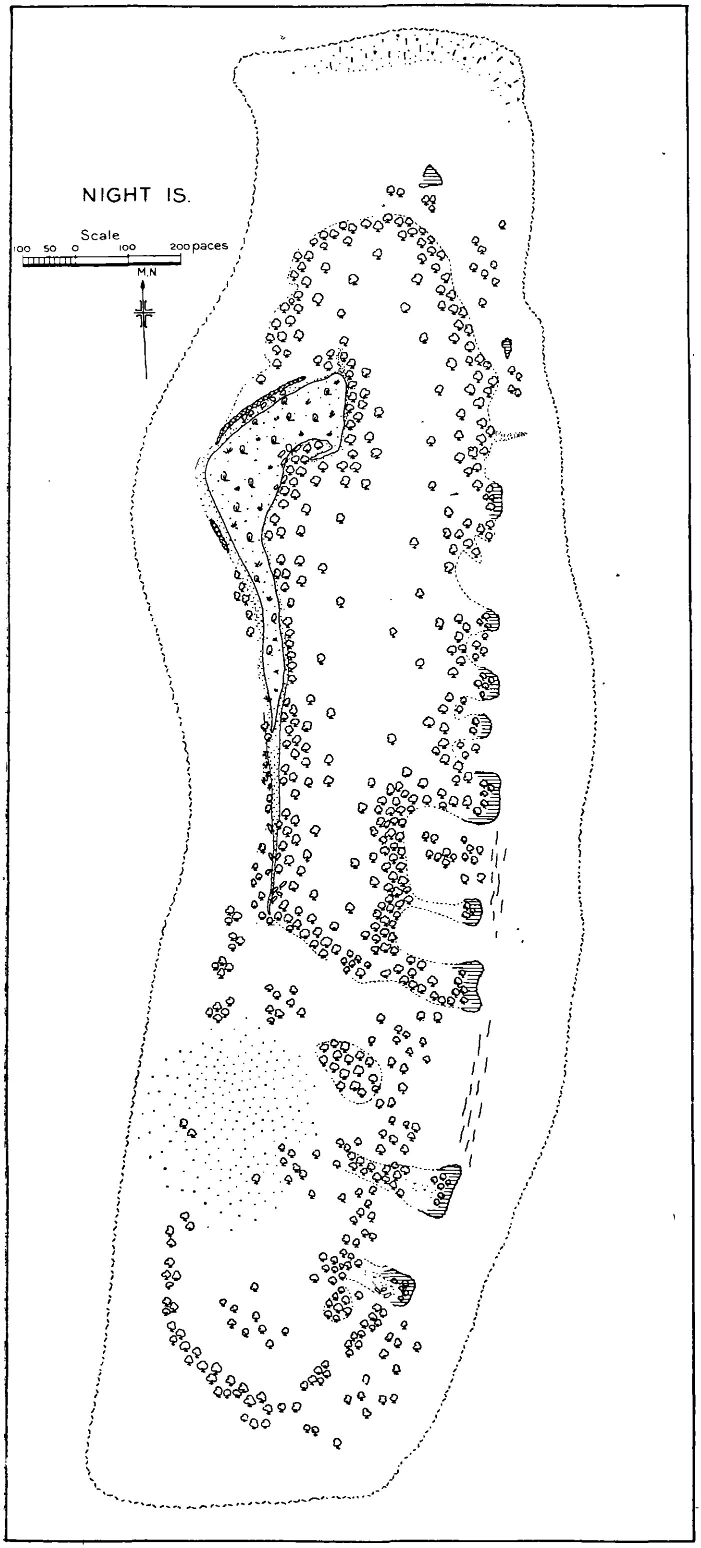
Pelican Island.—This is a normal sand cay on one of the inner reefs. It is rather larger than most similar cays, and carries some beach-rock. The reef-flat near the cay is sandy, much of the sand having been blown from the cay during cyclones. The vegetation consists mainly of creeping plants and grasses, with a few bushes. At the time of our visit (25th June, 1936) the waves had built a short and well-recurved sand spit at the north-western corner of the cay.

Fife Island.—The Admiralty charts give a fairly large-scale plan of this reef. The outline of the reef on Kemp's map is enlarged from the chart; the cay itself was re-mapped. It is a large cay, with a good deal of beach-rock on its southern side. There was nothing unusual in the cay itself. The vegetation consisted of grasses, creeping plants, and bushes. The following were collected, and later identified by Mr. W. D. Francis, of Brisbane:—*Abutilon* sp., *Capparis lucida*, *Solanum viride*, *Scævola frutescens*, *Josephina grandiflora*, *Tribulus cistoides*, *Canavalia obtusifolia*, *Polanisia viscosa*, *Euphorbia atoto*, *Spermacoce* sp.

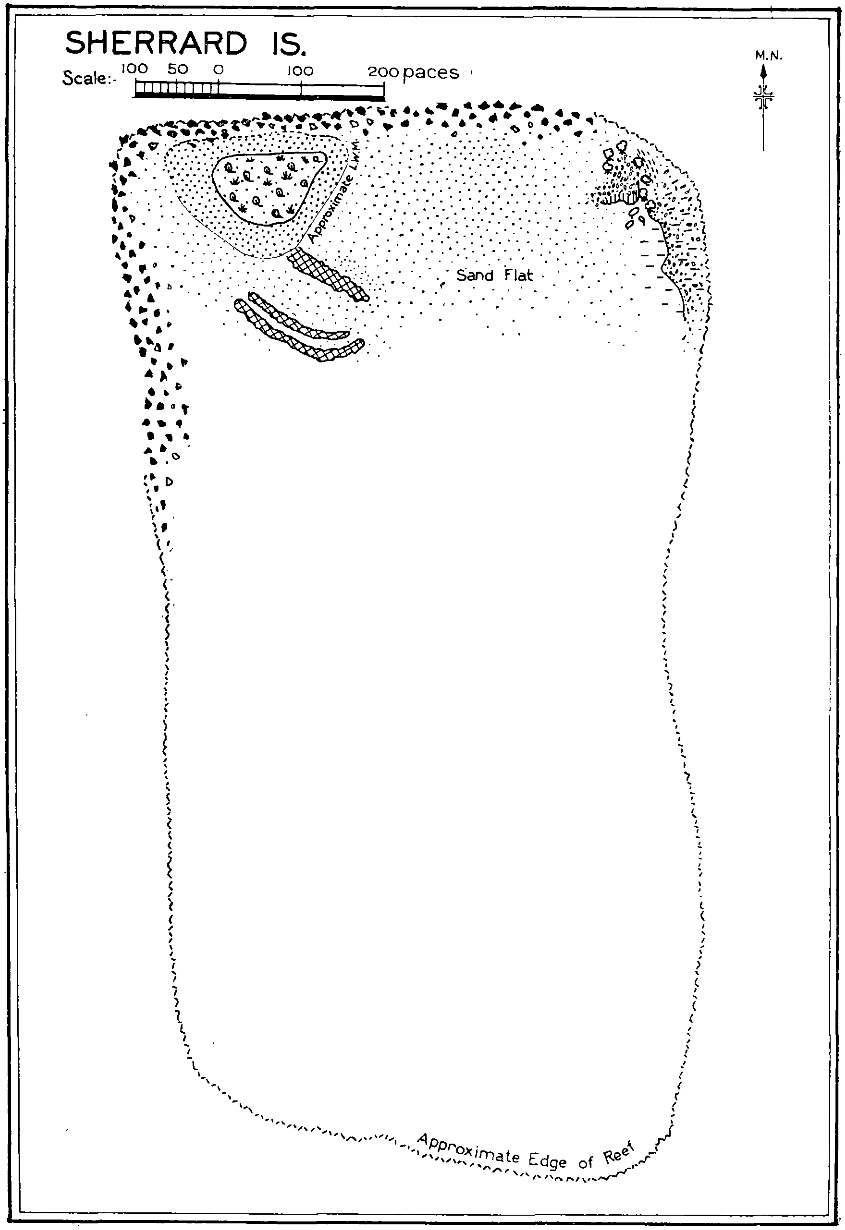
The reef-flat, especially near the cay, was very sandy (cf. Pelican Reef). A long sand-ridge, awash at high water, ran north-eastwards from the cay. There were many birds resting on the cay.

Night Island.—There are several points of interest to be seen on this reef, which is elongated north and south and lies close to the mainland a few miles south of Cape Direction. The cay, formed of sand, stands on the lee side of the reef, and is also stretched out in a meridional direction. It is clearly separated from the mangroves, and is well covered with vegetation—trees, grasses, and creeping plants. A certain number of coconut palms have been planted in the last year or so. There are poor stretches of beach-rock along its western margin, and a far better development just off the north-western margin. This patch is separated from the cay by a narrow belt of mangroves. To the south the cay tapers and eventually becomes a narrow sand spit which gives every impression of being a very recent construction. The eastern side of this spit is steep, and it is clearly invading the mangroves. A few years ago (perhaps as many as twenty) the island was devastated by a cyclone, and many mangroves were blown down. Their remains are still strewn along the western shore of the cay and elsewhere. At the present time (June, 1936) the mangroves are grouped in big and high clumps alternating with large open areas of reef-flat that are being recolonized by *Rhizophora*. This gives a park-like aspect which is more marked than in most islands. The mangrove area is extensive, and encloses the cay on all but its western side. The clumpy aspect of the mangroves is best seen in the southern and south-eastern parts of the reef.

There is a noticeable absence of shingle ridges on this island. The weather side affords good developments of the lower platform, but, as can best be seen from the map, it is very discontinuous. There are, in fact, eleven separate platforms, and their conformation and appearance do not suggest that they ever were continuous. There is usually very little shingle on these platforms, and only on the two most southerly of them can anything approaching a shingle cay be said to exist. On these two there would probably be minute areas of dry land during the highest spring tides. The platforms are all quite normal; their upper surfaces are sometimes well-worn, and basset-edges (often prominent) are forming on them. *Suriana* is nearly always present.


NIGHT IS.
Scale
100 50 0 100 200 paces
M.N

Algal terraces between the platforms and the outer edge of the reef are prominent. Occasionally there are drops of 6 inches from one to another. Rampart shingle on the east and south-east of the



reef is, to all intents and purposes absent. There is also no real moat. At the north-eastern end of the reef there is a pronounced outer rampart, and a moat occurs inside it. To the north-west of the reef the mangrove mud has spread, and seems to have killed much of the reef. Incidentally, much of the whole area covered by the mangroves was sandy; there was also abundant *Thalassia.*

Whilst the upper surface of the reef seems to be largely moribund, the general appearance of much of the cay and mangrove area is one of recovery and rejuvenation after a severe blow.

Natives visit the island frequently. Small coasting steamers call at the anchorage between the island and the mainland to make contact with the mission station near Cape Direction.

Sherrard Island.—Although both the sand and shingle islets are very small, and the reef itself is not a large one, Sherrard Island is well worth visiting. The two islets (cf. Night Island) are almost east and west of one another, and stand close to the northern end of the reef. Changes have certainly occurred in the sand cay. The present cay is sandy, and carries a few small bushes, creeping plants, and grasses. Just south of it are three long lines of beach-rock which must, at an earlier time, have enclosed a cay. Now they merely enclose a sand-flat on which a little water stands even when the tide is out. The present cay has no beach-rock around it. The lines of beach-rock to the south are excellently preserved, and suggest that a former cay was washed out from them by a cyclone.

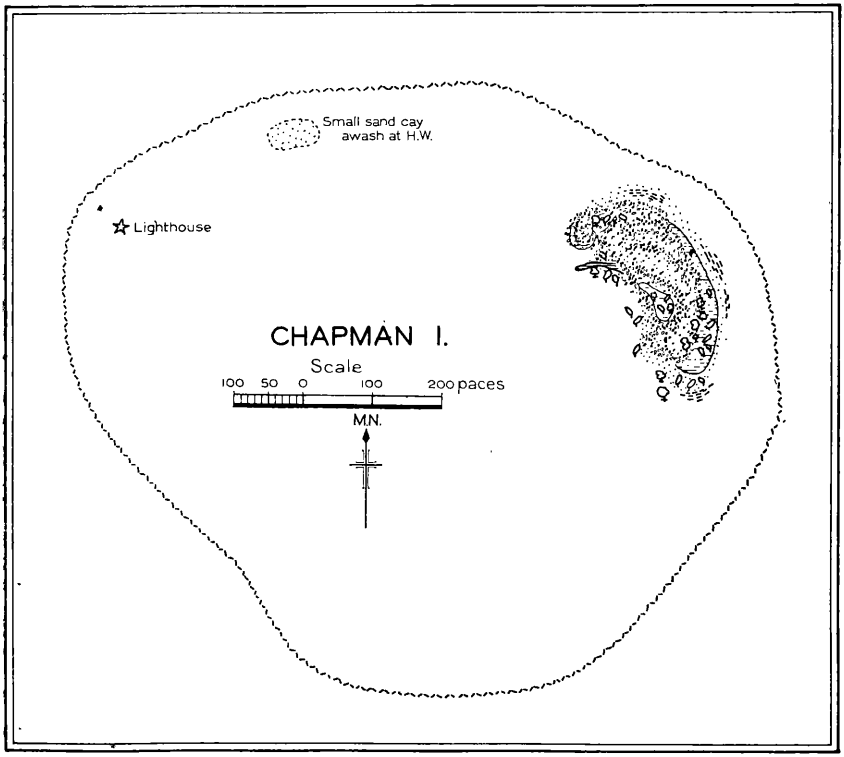
The reef-flat between the two islets is very sandy, and the northern end of the reef is strewn with boulders, forming a definite "moraine." It is true that boulders also fringe other parts of the reef, but they are most conspicuous here.

The shingle cay is small. There is an outer zone of shingle ridges, then a moat, and finally a platform with *Avicennia* and *Sesuvium* growing on it. Inside, and on the platform, are the shingle ridges of the true island, which is meagrely vegetated. Under the lee of the islet there are a few *Rhizophora,* but only two well-grown trees. They are, however, in the position normally occupied by the mangrove swamp. The shingle cay is made of coarse material.

Chapman Island.—This was the most northerly island visited. There is only one island here—the shingle island. It is built of shingle arranged in ridges, and the interior seems to have been excavated, possibly for guano. There are some remnants of the lower platform which, in parts, has been worn down into basset-edges. There is a scanty development of mangroves, some of which grow in hollows between newer and older shingle ridges. *Avicennia* and *Sesuvium* occur on the platform.

There is no true sand cay, but its place is occupied by a small sandbank which is awash at high water. This bank is in the position which the cay would normally occupy, and may be regarded as an embryo cay. The lighthouse (automatic) stands near the western margin of the reef.

(The general absence of an anchorage in the reefs on which low-wooded islands stand will have been noted. Experience certainly showed that an anchorage such as occurs at Low Isles, off Port Douglas, is rare. But if time and circumstances had permitted detailed surveys



of the *reefs,* incipient embayments would sometimes have been shown on the maps. But they would not have resembled the feature at Low Isles, and on the islands visited, would not (with the exception of Eastern Hope Island) have afforded shelter for even a very small boat.)

APPENDIX.

The following notes by Mr. H. G. Stubbings, B.A., Scholar of St. Catharine's College, and a research student in the Department of Zoology, Cambridge, deal with a small amount of material collected from certain reefs. Mr. Stubbings has worked intensively on the collections of the John Murray Expedition (1933-34), and is in a position to make some interesting comparisons.

It should be stressed that the Geographical Expedition to the Great Barrier Reefs in 1936 was not concerned with collecting zoological or other material, but Mr. Stubbings's report on the few samples brought back may be of use to future workers, and are therefore placed on record. I should like to acknowledge my personal thanks to Mr. Stubbings for the care he has taken in his report.

Marine Sediments from Islands and Reefs of the Great Barrier Reef.

By H. G. Stubbings, B.A. (Cantab.), B.Sc. (Lond.), Late Scholar of St. Catharine's College, Cambridge.

The small collection of samples described below was collected by Mr. J. A. Steers on a visit to the Great Barrier Reefs in 1936. They consist entirely of samples of sands from various beaches and lagoons, some being merely surface deposits and others obtained by shallow borings a few feet in depth. Owing to the small number of samples (systematic collection was not undertaken), it is not possible to compare samples from different areas to any extent. The very small size of many of the samples is an additional drawback, especially in the case of the short series taken by boring, as any differences in composition noted may be more apparent than real, and would probably disappear if larger amounts of material were available. Especially is this the case with the several series of samples taken in the lagoon of Lady Musgrave Island.

In the present paper no attempt has been made at mechanical analysis. The present work is entirely directed towards determining the origin of the materials forming the deposits. Apart from small quantities of quartz in some of the samples, the material is of organic—chiefly animal—origin. As far as possible, the contributory animals have been identified. The lists of Foraminifera are not claimed to be in any way complete; many fragmentary and worn forms are specifically unidentifiable, and in some cases small forms, unimportant as constituents of the sands, have not been identified.

Houghton Island.

Bore, depth 1½ feet.

The sample consists of coarse and fine gravel and fine sand formed almost entirely of coral and Molluscan shell fragments. A few examples of the Foraminifera, *Tinoporus baculatus* Carpenter and *Orbitolites* sp., are present. Rare fragments of Echinoderm spines and Alcyonarian spicules occur.

Sherrard Sand Cay.

Foraminiferal sand, depth 0 feet.

This sand, as the following analysis shows, is composed largely of the shells of Gasteropoda, with Foraminifera the next main component:—

Gasteropoda.	Foraminifera.	Halimeda.	Crustacea.	Polychæt Tubes.	Alcyonarian Spicules.	Echinodermata.	Unidentified.
222	116	12	7	1	1	1	86

The Foraminifera consist chiefly of *Tinoporus baculatus, Orbitolites* sp., and *Rotalia* sp. Apart from the two first species, this group is very rare in the sand. *Tinoporus baculatus* is very common. A few rare fragments of coral are present.

HUNTER ISLAND (DUKE GROUP).

Foraminiferal sand, depth 0 feet.

The main constituents of this sand are Foraminifera, of which the most abundant is *Alveolina boscii* (Defrance). The whole sample consists of highly polished grains, making identification very difficult. The majority of the specimens of *Alveolina* are fragmentary. Skeats (1918, p. 87) states that this is a shallow water Foraminiferan found down to 30 fathoms, below which depth it is rare. In the Barrier Reefs region it would appear to be considerably restricted in its distribution, as this is the only sample in which the species was not rare or absent. A few other Foraminifera, including *Nummulites cumingii* (Carpenter) and *Orbitolites* sp., occur sparingly. There are no specimens of *Tinoporus baculatus* in this sample.

Shell, mainly Gasteropod, fragments are quite common, but are much less abundant than Foraminifera. A very few Alcyonarian spicules are present.

PICKERSGILL REEF.

Three samples were collected from this reef.

(i.) Depth 12 feet, ¼ mile from cay.

A very fine grey calcareous sand composed of shell and coral fragments. Only a few large fragments, chiefly remains of *Halimeda* or Lamellibranch valves, are present. The finer material contains Alcyonarian spicules, which are quite common, and a few triradiate Poriferan spicules. There are a few Foraminifera, including *Tinoporus baculatus*, *Quinqueloculina* sp., and *Orbitolites* sp. Only one of each of these was seen. A few badly worn Rotaliids are also present. The deposit is composed entirely of calcareous organic remains.

(ii.) Depth 21 feet, 700 yards from cay.

A very fine grey calcareous shell sand. The material is composed almost entirely of shell and coral fragments and Alcyonarian spicules. Foraminifera are exceedingly rare. *Tinoporus baculatus* is absent. A very few intact minute Gasteropod shells are present. This sample is similar to (i.), as is to be expected, since they are from similar situations.

(iii.) Depth 4 feet.

A coarse sand composed entirely of shell remains and Foraminifera, almost all of which are *Tinoporus baculatus*. Alcyonarian spicules are fairly common, but other constituents are rare. Other minor components include *Halimeda* segments, a few fragments of other coralline algæ, several further species of Foraminifera, and a few small intact Gasteropod shells.

The majority of the shell fragments are too small to enable me to determine whether they are of Gasteropod or Lamellibranch origin. There are probably also a few minute coral grains present.

PIPON ISLAND.

The material collected consists of—

(i.) A small sample from a boring in coral conglomerate (*i.e.*, part of the lower platform) at a depth of 3 feet;

(ii.) Samples from a boring in the sandy mangrove flat. Four samples were taken from depths of 0, 1, 2½, and 5 feet.

(i.) Bore in coral conglomerate, depth 3 feet.

The material is only partly conglomerated, and consists of fine sand and gravel and a few larger fragments consisting mainly of coral débris with a few Molluscan fragments.

The sand and gravel consists mainly of Gasteropod and Lamellibranch shells and their fragments. Alcyonarian spicules are frequent. Rare fragments of Echinoderm spicules and Polychæt tubes occur.

Foraminifera are quite common, *Tinoporus baculatus* being commonest. Other Foraminifera are represented by worn, infrequent specimens, and include (?) *Nummulites* sp., *Clavulina* sp. aff. *C. angularis* (d'Orbigny), *Rotalia calcar* (d'Orbigny), *Rotalia* sp., *Quinqueloculina* sp., *Orbitolites* sp. (fragment), *Planorbulina* sp. The last is quite frequent.

(ii.) Bore in sandy mangrove flat.

(*a*) Depth 0 ft.

A fine calcareous sand composed chiefly of shell fragments. A few larger shell and coral fragments are present, and a number of Foraminifera, of which *Planorbulina* sp. and *Tinoporus baculatus* are the commonest. The following species, also, are present:—*Polystomella* sp., *Nummulites cumingii, Quinqueloculina reticulata* (d'Orbigny), *Cymbalopora tabellæformis* Brady, *Orbitolites complanata* Lamarck. Alcyonarian spicules are infrequent and Echinoderm remains absent.

(*b*) Depth 1 foot.

A calcareous sand and gravel containing more large fragments, chiefly of dark altered coral, than the preceding sample. The material generally is coarser, there being less fine sand than in the surface sample. The component organisms are similar. Small *Orbitolites complanata* appear to be commoner, and Echinoderm spicule fragments are frequent. A few unidentified Miliolids were seen.

(*c*) Depth 2½ feet.

This sample contains still more of the coarser material, but the remainder is all fine calcareous sand, as in the surface sample, and finer than that found above it at a depth of 1 foot. There are fewer *Orbitolites*, but the specimens are mainly much larger. A single *Calcarina spengleri* (Linnæus) was found in this material. Other Foraminifera were the same as in the previous material.

(*d*) Depth 5 feet.

A coarse calcareous sand or fine gravel. Large fragments are common, and the general texture is much coarser. The following Foraminifera, not found in the surface deposit, occur here:—*Alveolina boscii, Orbitolites complanata, O. marginalis* Lamarck (one fragment only), *Bulimina* sp., *Cymbalopora* (?) *poeyi* (d'Orbigny), *Calcarina spengleri, Peneroplis pertusus* (Forskal). *Cymbalopora tabellæformis,* found in the surface deposit, is absent here.

There is thus very little variation in the composition of this deposit throughout the depth examined (5 feet). The small variations in coarseness of the deposit are probably not significant, as the samples are very small. In larger samples these differences would probably not be appreciable. It is perhaps worthy of note that almost all the species of *Foraminifera* found in the surface layer occur at the lower levels, but that in the lower levels a number of additional species not found higher up occur. This is especially noticeable in the lowermost sample, where at least seven species not present in the other samples were found.

How far these differences indicate differences in the Foraminiferan fauna living on or near the flat it is difficult to say. If more complete identifications had been made on a larger amount of material, many more Foraminifera would probably have been noted, and differences such as that between the lowest and more superficial samples would probably have been less apparent. Also, the species found only in the lowest sample are nearly all comparatively massive forms, and their presence here may be due merely to sorting of the material as it settled, the heaviest species naturally sinking before the smaller and lighter ones.

Lady Musgrave Island.

(i.) *Soil sample.*

A specimen of ''soil'' consisting chiefly of decayed organic (plant) material and small calcareous grains. The latter are cemented together by a white substance apparently of the nature of guano. In the material, fish vertebræ, fragments of other bones, and a few otoliths are to be found, indicating that part at least of this material has been deposited by fish-eating birds—*i.e.*, it is guano.

(ii.) *"Beach rock" from south corner.*

This material consists mainly of coral impregnated with a brown material which cements some of the sand together, forming the so-called "beach rock." In the small sample collected, consisting of small lumps, it is noticeable that each lump consists of a fragment of impregnated coral with a small amount of the finer cemented material adhering to it. It would appear that this rock is almost entirely of coral origin, with only a small amount of non-coral material filling up the spaces between the fragments of coral.

(iii.) *Lady Musgrave Lagoon.*

Twelve samples were collected in this lagoon. The approximate positions from which they were taken are shown on the sketch-map. The numbers on the map and in the text agree. The actual sampling was made at three different times, corresponding with I.-IV., V.-VII., and VIII.-XII., as shown in the sketch.

(i.) Depth 21 feet.

This sample is very similar to the two following. Minute reddish fragments are present in this and the two following samples. Some are of Molluscan origin, and others apparently are derived from *Tubipora.*

(ii.) Depth 26 feet.

A similar deposit to the above, only slightly coarser. Minor components are the same as in the previous sample, with the addition of rare fragments of *Orbitolites complanata.*

(iii.) Depth 27 feet.

A very fine shell and coral sand with very few coarse fragments, similar to that described from practically the same depth at (ii.) above. The quartz in this material is finer than in certain of the following samples. Animal remains, other than shell and coral débris, are very uncommon. A few rare examples of the following were obtained:—*Tinoporus baculatus, Quinqueloculina* sp., Echinoderm spines, and Alcyonarian spicules.

The three samples collected on this side of the lagoon show very little change in composition or texture on moving into deeper water. The shallower samples are slightly coarser, as is to be expected, as the coarser materials would be deposited first as the power of the waves diminished with the increase in depth of the water. The difference in particle size is less than is found in other positions where the difference in depth is no greater.

(iv.) Depth 28 feet.

A very fine, creamy, calcareous sand similar to that from 27 feet ((iii.) above). In the samples hitherto examined Alcyonarian spicules have been rare and represented by odd, usually broken, large white spicules. In this deposit, however, Alcyonarian spicules are much more frequent and represented by very small cherry-coloured specimens. These are very common, and give the sand its cream colour, the other materials being mainly white. White spicules are present as in the other samples. Foraminifera are extremely rare, and represented by fragments of small species only. Fine quartz grains are again present in this sample.

(v.) Depth 10 feet.

A shell and coral sand, somewhat coarser than the last. Quartz grains were not found after dissolving out the calcareous matter from a small sample. This mineral may, however, be present in very small amounts, as it occurs in all the other samples examined from this area. In addition to the animals found in the previous sample and listed above, the following rare remains were identified:—*Tubipora,* small *Foraminifera,* Echinoderm spine fragments, and spicules of Porifera and Alcyonaria. The following large species of Foraminifera were found:—*Calcarina spengleri, Tinoporus baculatus, Orbitolites marginalis, Textularia gramen* (d'Orbigny), *Cymbalopora* sp., *Quinqueloculina* sp., *Polystomella* sp. *C. spengleri* is the most frequent of the above species, though it is by no means common. The other species are all very rare.

(vi.) Depth 25 feet.

A shell and coral sand somewhat coarser than the above. A few *Tubipora* fragments are definitely identifiable, also a few fragments of *Polytrema* sp. This Foraminiferan is apparently very rare in Barrier Reef sands in contrast with similar shallow water sands from the Indian Ocean, where this organism is often very abundant. There are fewer red grains in this sand than in the preceding. The following occur as minor constituents:—Alcyonarian spicules, Ostracod valves, *Quinqueloculina* sp., Poriferan spicules, and fragments of *Orbitolites* sp., *Polytrema* sp., and *Tubipora*.

(vii.) Depth 27 feet.

A very fine, white, calcareous shell and coral sand. Small pink and red fragments are common. Some of these probably are derived from the coral *Tubipora*, though all are too small and worn to show any of the characteristic tubular structure of this coral.

Rather large and numerous quartz grains are present in this deposit. This must have been derived from older rocks and carried to this region. All the other constituents of the deposit are of organic origin. Foraminifera are represented by occasional worn specimens of *Tinoporus baculatus* and *Quinqueloculina* sp. and rare fragments of *Orbitolites* sp. Occasional Lamellibranch valves and Echinoderm spine fragments occur.

(viii.) Depth 30 feet.

This deposit is a very fine, cream-coloured sand. The colour is due to the presence of numerous pink and cherry-coloured Alcyonarian spicules. Foraminifera are absent except for a few small *Quinqueloculina* sp. and very rare fragments of *Polytrema* sp. A few fragments of Poriferan spicules are present; also fine quartz grains. The deposit is very similar to that from (iii.), depth 27 feet. None of the larger Foraminifera, such as *Tinoporus, Calcarina, Polystomella, Cymbalopora, Orbitolites*, or *Textularia*, are present. These species apparently only occur in numbers in the very shallow water of the lagoons in 2 to 3 fathoms.

(ix.) Depth 27 feet.

A fine sand coarser than that from 30 feet and coloured similarly. A number of brown and fawn grains are present. These appear to be coloured subsequent to collection by the rusting of the tin containing the sample. More quartz is present in this material than in the above. Large Foraminifera present include *Planorbulina* sp., *Textularia rugosa* (Reuss), *Quinqueloculina* sp., and *Polystomella* sp.

(x.) Depth 12 feet.

A shallower, and hence coarser, but still fine sand. Very few coloured Alcyonarian spicules are present, but triradiate Poriferan spicules are common. This is the only sample in the collection to contain any number of these spicules. Echinoderm spines and quartz grains are very uncommon. Foraminifera are represented by occasional specimens of *Orbitolites marginalis, O. complanata, Peneroplis pertusus, Calcarina spengleri, Cymbalopora poeyi, Textularia gramen*, and *Polystomella* sp.

(xi.) Depth 6 feet.

A coarse gravelly sand composed of coral, shell fragments, and Foraminifera. The coarse gravel portion consists of more or less intact Molluscan shells and green coral fragments. This green colour is due to the presence of the boring green algæ responsible for the breakdown of calcareous material, especially coral, in the sea. Fragments of the green coral and of a green Lamellibranch valve were decalcified with dilute acid and mounted. They showed the usual filaments of the green alga, recorded as living in calcareous material. The importance of these algæ as agents in the breakdown of coral and coral sand is discussed in references by Bertram

(1936, p. 1014), and as a factor in the disintegration of the shell of *Balanus balanoides* on the Isle of Man coast by Parke and More (1935, p. 54). The alga appeared to inhabit the outer part only of the coral, but to have pentrated right through the thin shell of the Lamellibranch mentioned above.

As in other shallow deposits in the collection, *Tinoporus baculatus* is very common. *Calcarina spengleri, Orbitolites* sp., and *Polystomella* sp. also occur sparingly. Ostracod valves, Echinoid spines, and triradiate Poriferan spicules are among the minor constituents.

(xii.) Depth 6 feet.

This sample is a coarse gravel or rubble composed of large shell and coral remains and a few pieces of dead *Lithothamnion*. There is no fine sand. All the material appears to be heavily infected with the green boring alga mentioned above.

Organisms Contributing to the Deposits.

1. *Major Constituents.*

It is seen from the above lists that the chief component of these sands is almost always the fragmentary remains of Mollusca, mainly Gasteropoda. Whole Gasteropod shells are always rare, and, if present, are usually of very small size. Lamellibranch shells are far less common, usually fragmentary or extremely minute. When larger valves are present they are usually fresh shells not yet broken by pounding on the shore. These shells appear to break up far more quickly than Gasteropod shells, doubtless due to the much lighter construction of many of them.

Although the deposits are from coral reefs, it is once again evident, as pointed out by previous authors, that the main constituent of a reef sand is not coral débris but some other constituent. Thus Thorp (1936, p. 115) has shown that on Pearl and Hermes Reef, Hawaiian Archipelago, about 50 per cent. of the sand is formed of coralline algæ. These organisms again are the commonest sand constituents on the Florida and Bahamas reefs, forming 25·1 per cent. and 18·0 per cent. of the deposit respectively. Here they are closely followed by Mollusca on the Florida reefs and Foraminifera on the Bahamas reefs, in each case with 1 per cent. less than the major component (Thorp, 1935, p. 52). Madreporarian corals only occupy fourth place (loc. cit. p. 93). Vaughan and Goldman (Vaughan, 1918, p. 258) found that in samples from Murray Island, Australia, coralline algæ were the chief components, Foraminifera second, and Madreporaria only third. Bramlette (1926, p. 6) found that calcareous algæ were the most important sand-forming organisms in Pago Pago Harbour, Samoa. Here Madreporaria were probably second, followed by Mollusca. Finally, Skeats (1918, p. 87) records that the material from the upper 180 feet of the Funafuti bore only contained about one-fifth coral, the remainder consisting of calcareous algæ, Foraminifera, and other organisms. Thus calcareous algæ appear to be the most important sand-forming organisms on most reefs so far investigated, the next in importance being Mollusca, Madreporaria, or Foraminifera. In the present Barrier Reefs samples, however, calcareous algæ are extremely uncommon, and were only recognised in one or two samples. The main component here is usually Molluscan fragments, except in a few localities—*e.g.*, Hunter Island, where Foraminifera are predominant. Coral débris may occupy second place in many of the sands described above, though the individual grains are often difficult to identify owing to their fine state of division compared with other organic remains. Coral is closely followed by Foraminifera, which frequently are the more abundant, as in the samples from Sherrard Sand Cay and Pickersgill Reef (iii.).

2. *Minor Constituents.*

Infrequent grains, referable to the following groups of organisms, were also present in some of the samples:—

Porifera, Polychæta, *Tubipora,* Alcyonaria, Echinodermata, Crustacea, Malacostraca, Ostracoda, *Halimeda,* Coralline Algæ.

None of the above are very common in any of the deposits. Poriferan spicules, chiefly of the triradiate type, occur in almost all the samples examined. An occasional monaxon or tetraxon spicule was found, but these are very rare. Alcyonarian spicules, usually simple, colourless forms, occur in nearly all the samples, though they appear to be absent in some parts of Lady Musgrave Lagoon. Three samples were obtained here containing abundant small, red foliaceous Alcyonarian spicules, though these form only a small percentage of the deposit on account of their small size. Fragments definitely referable to *Tubipora* were found in a sample from this lagoon, and three other samples from the same locality contained grains probably referable to this coral. Polychæt worm tubes and Malacostracan remains are extremely uncommon, being found together once only on Sherrard Sand Cay. Polychæt remains also occurred in the material from the bore on Pipon Island. In both localities they were very rare. Ostracod valves probably occur in many of the deposits, but are all extremely small and of no importance as contributors to the sand.

As already mentioned, algal remains are extremely rare in these sands. *Halimeda* remains were identified in sand from Sherrard Sand Cay and the three samples from Pickersgill Reef. Other coralline remains were found in the third sample from Pickersgill Reef only.

Echinoderm remains consist solely of spine fragments, and occur in practically every sample of deposit. They appear to belong to both Regularia and Irregularia. No fragments of the test were apparent in any of the samples.

Distribution of the Organisms.

In a small series of samples such as the present it is not possible to determine the depth distribution of the different organic remains with any accuracy. In the case of the Foraminiferian *Tinoporus baculatus*, however, the depth distribution is very distinct, as can be seen from the following table:—

Depth (feet).	Frequency.	Remarks.
0	very common	beach
0	..	beach on Hunter Is.
4	numerous	..
6	very common	..
10	frequent	..
12	very few	..
12	..	..
21	..	..
21	..	..
26	..	..
27	rare	Lady Musgrave Lagoon
27	rare	,, ,, ,,
27	..	,, ,, ,,
28	..	..
30	..	..

The absence of the species from the beach-sand on Hunter Island appears to be exceptional. The table clearly shows that the species is found from the shore-line down to a depth of about 2 fathoms, below which it is very rare and is represented by odd specimens only. Apparently this species lives in very shallow water in this region, where it is continually being moved by the waves as it lies on the sand. This would account for its frequent occurrence in the sand exposed to the air. On the other hand it does not seem to be moved much by the currents, as only a few specimens are carried into deeper water of 4 or 5 fathoms depth. This may, perhaps, be correlated with the dense nature of the test of this species, its more or less rounded shape and frequent lack of projections offering no resistance to sinking.

It is not possible to determine the range of other Foraminifera present in the deposits. Probably the majority extend throughout the depth range represented by the samples (5 fathoms). There are indications that *Calcarina spengleri* may be most abundant between 1 and 2 fathoms, though there are insufficient records to confirm or disprove this.

CONCLUSION.

The major proportion of the deposits in all the areas mentioned above appears to be a sand or sandy gravel of organic origin. In some places it appears to be entirely so. In a few, however, notably Lady Musgrave Lagoon, there is an appreciable amount of quartz present. This mineral is never very abundant, probably never exceeding 5 per cent., and is the only mineral present in the deposits.

No. 8.

THE GEOMORPHOLOGY OF EASTERN QUEENSLAND.

By C. A. Sussmilch.

(Plates XII-XIV.)

I. Introduction.

This paper is the result of a study of the geomorphology of the coastal regions of Eastern Queensland, undertaken with the object of determining, so far as possible, its physiographic history and its possible bearing upon the origin of the adjoining continental shelf upon which the Great Barrier Reef is built. For this purpose, a visit was made to Queensland recently, under the auspices of the Great Barrier Reef Committee, and detailed studies made of the coastal regions adjacent to (*a*) Rockhampton, (*b*) Townsville, and (*c*) Cairns; many useful observations of intervening districts were made, also, while journeying by train between these centres. The writer had previously carried out a fairly detailed study [24] of the geomorphology of the south-eastern part of the State (Moreton district), and the information obtained during that investigation was very helpful in the present one. Full use has also been made of the published work of previous observers; this work will be referred to in the next section.

II. Previous Observers.

In 1902 E. C. Andrews[1] published some notes on the geology of the Queensland coast, in which he discussed the origin of the coastal plains, the continental shelf, and some of the continental islands; he concluded that the continental shelf had resulted from a gradual subsidence with concomitant sedimentation. In 1910 he published a paper entitled "The Geographical Unity of Eastern Australia,"[2] which still remains the most important contribution we have had on the geomorphology of Eastern Australia as a whole. In this paper he claimed that the whole of Eastern Australia had acted as a unit during late Tertiary and Post-Tertiary time. He traced the physiographical history from the Miocene period to the present day, and was of opinion that a peneplain had been developed throughout the whole of Eastern Australia during Eocene and Miocene time, and that at the close of the Tertiary period a differential uplift took place which produced the present belt of tablelands. This uplift was accompanied, in his opinion, by marked faulting and warping and the production of great fault blocks, and that minor transverse faulting relieved the general peripheral strain. The continental shelf was considered to be a portion of the Tertiary land-surface which had been down-thrown and later modified by wave erosion and sedimentation. In the case of North Queensland he considered the whole of the coast from Hinchinbrook Island to Cooktown to have been strongly faulted or flexed beneath the sea; the Bellenden-Ker Range he considered to be a horst.

In 1933 Andrews[3] again stressed these views with regard to the origin of the highlands of Eastern Australia, but only makes brief reference to Queensland; he reaffirms his belief in the physiographic unity of Eastern Australia.[3]

T. W. E. David accepted these views of Andrews, for in 1914 he writes[9]:—"From Gladstone to Cape York there is a remarkable coast, chiefly of the ruckland type, with mountain ranges from 2,000 to 5,000 feet high coming mostly to the coastline and having high islands like Hinchinbrook, which rises to an altitude of 3,560 feet, close inshore. This part of the coastal shelf is so heavily faulted and studded with small islands which have survived the block faulting as to deserve Suess' title of 'Panzer-Horst.'"

No further contribution was made to the geomorphology of the Queensland coastal regions as a whole until 1928, when W. H. Bryan[6] published a description of the Queensland continental shelf which also included a brief description of some of the features of the coastal region. Two years later the same writer[7] published a general description of the physiography of Queensland in which the various geographical elements, including the coastal ranges and coastal plains, are briefly described. W. H. Bryan was apparently of the opinion that the main control in the production of the present topography has been differential erosion, controlled by the general strike of the geological formations.

In 1927-1928 F. Jardine published detailed descriptions of the physiography of certain parts of the coastal regions, such as (*a*) the Gladstone-Rockhampton district,[14] (*b*) the Townsville district,[16] and (*c*) the Cairns district;[15] except for the Mulgrave River corridor, which he considered to be a rift-valley; he assigned the origin of the various topographical features described by him to differential erosion.

In 1928 G. A. V. Stanley[23] published an excellent description of the physiography of the Bowen district, and came to the conclusion that the land forms of this district are to be explained as having resulted from differential uplift accompanied by block-faulting. The writer did not visit this district, but as its geographical features as described by Stanley are in accordance with what he has seen in other parts of Queensland, he has no hesitation in accepting Stanley's descriptions and conclusions.

III. The Tablelands.

The most important element of the geomorphology of Eastern Queensland is the continuous belt of tablelands which parallels the coast from the southern border to Cape York. It has a width ranging up to 300 miles or more. The general altitude varies; at the southern border the 3,000-feet level of the Northern Tableland of New South Wales continues into Queensland, and is well developed in the Stanthorpe district; between Dalveen and Warwick the surface drops rather suddenly down to the 2,000-feet level of the Darling Downs Tableland. In Central Queensland the general altitude is still lower, averaging about 1,300 feet just west of Rockhampton (Mount Morgan Tableland); west of Townsville, also, the average altitude is from 1,300-1,500 feet. Immediately to the north, however, the altitude rises to 3,000 feet, and from here to Cairns the altitude varies from 2,500 to 3,000 feet, culminating in the Bellenden-Ker Range, where it reaches over 5,000 feet. It is worthy of note that it is in Central Queensland, where the tableland is widest, that it has the lowest altitude; and it is here, also, that the continental shelf is widest.

The original surface of these tablelands was, by E. C. Andrews,[2] in 1910, considered to be a peneplain developed during the Tertiary period and uplifted to form them at about the close of that period. J. V. Danes,[8A] who had made an intensive study of the physiography of the northern tablelands of Queensland, supported Andrews' view, and made frequent reference in his writings to this Tertiary peneplain. The existence of this peneplain in the Charters Towers Tableland had been referred to by Wm. Poole as far back as 1906.[20]. In 1930 the present writer[24] made reference to the presence of this peneplain in the Moreton district of South-Eastern Queensland, and quoted evidence in support of its existence there. He has also seen evidence in the field of its existence in the Stanthorpe Tableland (Southern Queensland), on the Mount Morgan Tableland (Central Queensland), as well as on many of the lowlands of Eastern Queensland to be described in this paper.

Proof of the existence of this Tertiary peneplain is afforded, also, by many of the geological sections published by various writers on the geology of Queensland, a few examples of which may be quoted.

J. H. Reid and C. C. Morton[27] have published an east-west section across the Central Tableland extending from the coast at Rockhampton to Blackall, which displays an erosion surface cut indifferently across formations ranging from Lower Palæozoic to Cretaceous in age and now standing at altitudes ranging up to 1,500 feet above sea-level. G. A. V. Stanley's[23] description of the geology and physiography of the Bowen district gives evidence that the original surfaces of the tablelands of that district were a peneplain now standing at an average altitude of about 3,000 feet. The geology of the Roma-Springsure district has been described by H. I. Jensen,[28] and his sections show the presence there of a well-marked peneplain developed alike in the Palæozoic and Mesozoic strata of that district. H. C. Richards, in his description of the volcanic rocks of the Springsure district[21A] also shows a well-developed peneplain there in Permian strata overlain by Upper Tertiary lava flows. Similar evidence, also, can be found in North Queensland; H. I. Jensen's description of the geology of the Cairns hinterland[29] includes an east-west section from Cairns, on the coast, inland to Forsayth, a distance of over 200 miles, which shows conclusively a well-developed peneplain throughout its whole length cut out of Palæozoic strata and their associated plutonic rocks, and capped in places by extensive Upper Tertiary basalt flows.

It has been considered necessary to quote this evidence because the existence of this Tertiary peneplain in Queensland has been questioned by some geologists, notably J. H. Reid[30, 31, 32]; A. K. Denmead and W. H. Bryan[11]; and E. O. Marks[19, 33, 34].

These tablelands have, since their elevation, suffered considerable dissection, and the original peneplain surface has in most places been largely destroyed, but its former existence is still evidenced by the fact that in many of the tablelands, particularly in the regions of folded strata and associated plutonic rocks, the ridges all rise to an approximately similar altitude.

In favourably situated localities, however, considerable areas of their original surfaces still, in the writer's opinion, survive, and give one a picture of the topography of the land surface as it existed before the present-day tablelands were uplifted; a description of this late-Tertiary topography is desirable, since it supplies important evidence as to the origin of some of the present-day land forms.

The writer has studied many of these tableland-surface remnants in New South Wales, and has seen sufficient examples in Queensland to have no hesitation in saying that their features in Queensland generally are similar to those of New South Wales. In both States the features are everywhere the same, quite regardless of wide differences in altitude and differences in geological structure. Many of the examples studied occur in regions of highly folded Palæozoic strata with their associated plutonic intrusions; others occur in horizontal or gently folded Mesozoic strata, while still others occur in Tertiary volcanic rocks.

The surface topography of these undissected tableland surfaces is found to consist of the following elements:—

(*a*) A series of low, rounded ridges and isolated hills, all rising to a common level, which is usually about 300 to 400 feet above the bases of the intervening mature valleys; seen from a distance, the summits of these ridges present a very even sky-line. These hills are well covered with soil, and bare rock outcrops are the exception. The fact that the ridges just described all rise to a common level over extensive areas, particularly in regions of highly folded strata, is strong presumptive evidence that their tops are remnants of a peneplained surface.

(*b*) A series of broad, flat-floored, mature valleys, 300-400 feet deep, lying between these ridges. These valleys are all more or less aggraded, and range up to several miles in width. E. C. Andrews[2] was the first to draw attention to these mature valleys lying on top of the tableland surfaces, and referred to them as the "upland valleys." This combination of ridges and valleys represents a thoroughly mature topography, which is in strong contrast to the youthful topography of the valleys of the present-day streams where they are cutting their way headwards into these undissected tableland remnants.

The evolution of a topography such as that described would obviously require a long period of geological time for its development, and would necessitate the following stages:—(1) A cycle of erosion, with the development of a peneplain at or near sea-level; (2) an uplift of 300 to 400 feet, converting the peneplain into a tableland; (3) an incomplete cycle of erosion, during which the mature valleys were developed; (4) a small subsidence, following which the valleys' floors were aggraded. It should be mentioned here that the first cycle of erosion referred to did not produce complete peneplanation, because remnants of the tableland out of which the peneplain was cut still survived in many places in the form of monadnocks and short narrow ridges rising above the peneplain level at the close of the cycle. Such residuals in New South Wales vary from 450 to 1,500 feet in altitude, according to the height of the original tableland out of which the peneplain was cut. The writer has seen similar residuals in Queensland.

These events are considered to have taken place during the Tertiary period, and it is believed that at the close of this period a topography such as has been described existed over the whole of Eastern Australia; this topography may therefore be conveniently referred to as the late-Tertiary topography. The land surface on which it occurred was, in the writer's opinion, uplifted to form the present-day tablelands at the close of the Tertiary period. The writer considers that this Tertiary topography still persists to-day, not only on some parts of the tablelands, as has been described, but also, as will be pointed out later, on certain low-lying coastal areas.

In the descriptions which follow of those low-lying areas whose surfaces display a topography similar to that just described, it will be convenient to refer to it as a late-Tertiary topography, because there is no other simple term which will indicate just what is meant, it being understood, of course, that it is purely the writer's interpretation in each case.

The present-day tablelands do not in Queensland extend right to the shore-line (with one small exception), except in the region north of Cairns, but between the main tableland and the coast there lies a series of coastal plains and coastal ranges to be described in the next section.

IV. Description of Typical Queensland Coast Sections.

It is proposed here to give a brief description of a number of sections taken from various parts of the Queensland coast from Cairns southwards to Brisbane for the purpose of illustrating the various elements of the geomorphology. The writer has not visited that part of the coast northwards from Cairns, but this part of the coastal regions has already been described by H. C. Richards and C. Hedley.[21]

The accompanying sketches (Figs. 1, 2, and 3) are only approximately to scale, and are quite diagrammatic; on account of the small scale, it has been necessary to exaggerate the depth of the ocean, and also the steepness of the scarps. No attempt has been made to show the details of the dissection which the tablelands and coast ranges have suffered since their uplift. They are, of course, not flat, as shown.

A. Section at Buchan Point, North of Cairns.

The tableland here, which has a general altitude of about 2,500 feet, ends abruptly at the sea-coast, there being no coastal plain.

B. Section at Cairns.

This differs from the previous section in the presence of a flat coastal plain between the tableland and the sea (see Fig. 6, Plate XII.). with a width of 2 to 3 miles and an elevation of less than 50 feet above sea-level; its surface is aggraded. The coastal margin of the tableland appears to be step-faulted, the lower step (Whitfield Range) having an altitude of about 1,250 feet; the main tableland has an altitude averaging about 3,000 feet.

C. Section at Bellenden-Ker Range.

This section shows the following elements:—(*a*) The Main Tableland (Atherton Tableland); (*b*) the Bellenden-Ker Tableland; (*c*) the Mulgrave River corridor; (*d*) the Coastal Range (Malbon-Thompson Range).

(*a*) The Atherton Tableland has a general elevation of about 2,400-2,500 feet, and has been described by Jardine.[15]

(*b*) The Bellenden-Ker Tableland is much higher than the Atherton Tableland, ranging in altitude from 4,000 feet at its northern end (Lamb's Range) to 5,287 feet at its southern end (Bartle Frere).

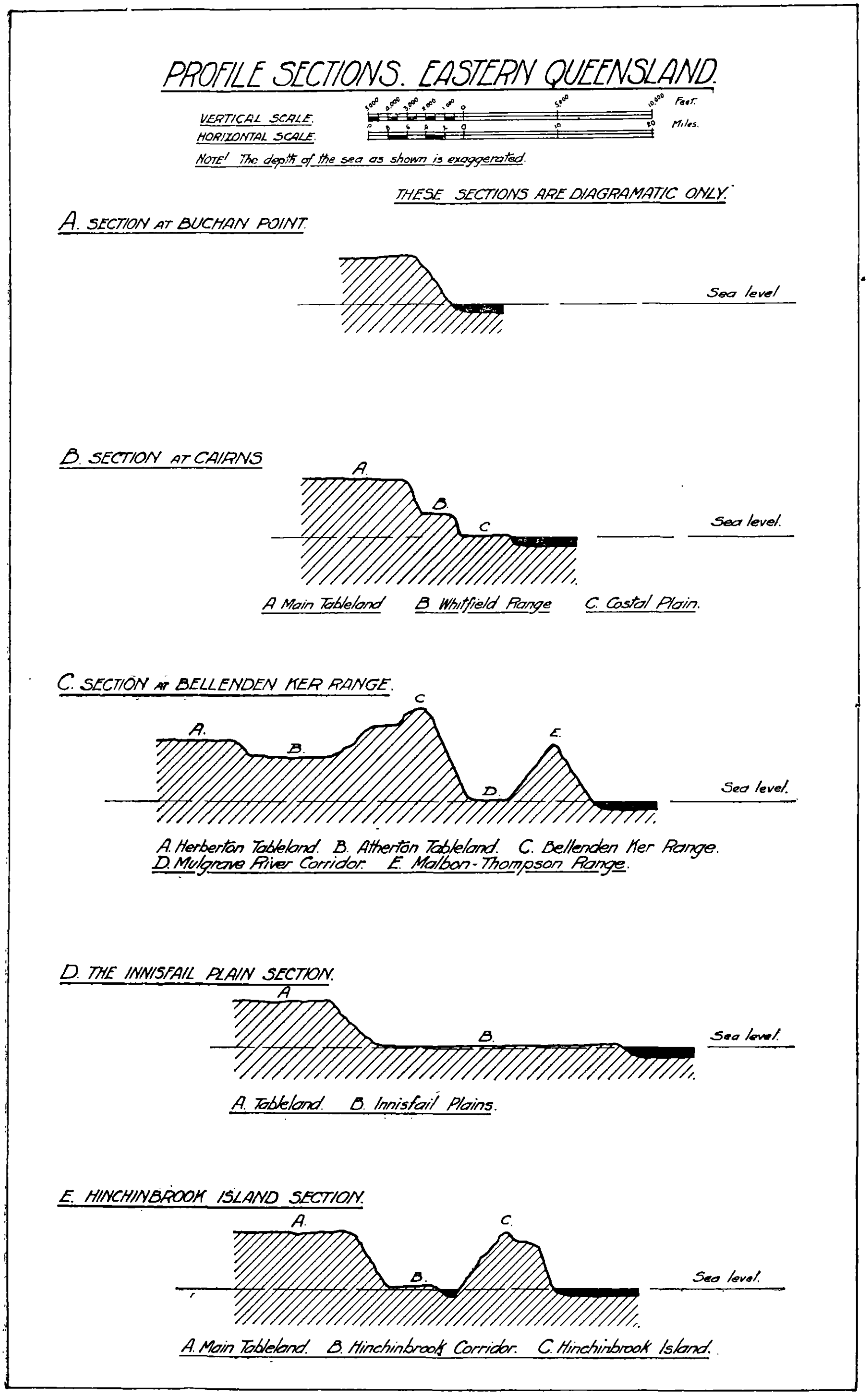

PROFILE SECTIONS. EASTERN QUEENSLAND.
VERTICAL SCALE.
HORIZONTAL SCALE.
Feet.
Miles.
NOTE! The depth of the sea as shown is exaggerated.
THESE SECTIONS ARE DIAGRAMATIC ONLY.
A. SECTION AT BUCHAN POINT.
Sea level
B. SECTION AT CAIRNS
A.
B.
C
Sea level.
A Main Tableland B Whitfield Range C. Costal Plain.
C. SECTION AT BELLENDEN KER RANGE.
A.
B.
C
D.
E.
Sea level.
A. Herberton Tableland. B. Atherton Tableland. C. Bellenden Ker Range.
D. Mulgrave River Corridor. E. Malbon-Thompson Range.
D. THE INNISFAIL PLAIN SECTION.
A
B.
Sea level.
A. Tableland. B. Innisfail Plains.
E. HINCHINBROOK ISLAND SECTION.
A.
B.
C.
Sea level.
A. Main Tableland. B. Hinchinbrook Corridor. C. Hinchinbrook Island.

FIG. 1.

Its width in an east-west direction is about 10 miles. Although it is the highest mountain block in Queensland, it lies many miles to the east of the Main Divide. It is bounded by steep scarps on both sides, particularly so on its eastern side. E. C. Andrews considered it to be a horst,[2] while Jardine refers to it as a residual.[15]

(*c*) The Mulgrave River Corridor.—Ths has already been described in some detail by both Danes[8] and Jardine;[15] it has a length of about 44 miles and a width of about 4 miles. Its surface is almost quite flat, and is covered by alluvial deposits (see Fig. 7, Plate XII.); borings near Cairns show that this material continues downwards to at least 100 feet below sea-level, but just how much deeper is not known. The flat floor of the corridor makes an abrupt junction with the steep mountain scarps on both sides. Danes and Jardine were both of opinion that this feature was a rift-valley.

This feature was termed a corridor by Jardine, and, as the name is very descriptive, it has been retained here for this and other similar physiographical features.

(*d*) The Coastal Range (the Malbon-Thompson and Graham Ranges).—This feature lies between the Mulgrave River corridor and the ocean, and has a width of about 4 miles. In its wider portion (Malbon-Thompson Range) it reaches an altitude of 3,317 feet, the altitude decreasing southwards. Along its western side it presents a very steep, straight scarp to the adjoining corridor.

These three features—viz., the Bellenden-Ker Range, the Mulgrave River corridor, and the Coastal Range—are markedly parallel to one another, with a trend of N. 30° W., and a length in this direction of about 44 miles; all three end abruptly at both their north and south ends. The Bellenden-Ker Range at its northern end abuts against a tableland at least 1,000 feet less in altitude, while at its southern extremity it ends abruptly against a low plain (the Innisfail Plain), to which it presents a very steep scarp (see Fig. 8, Plate XIII.). The coastal range at its northern extremity ends abruptly against the ocean (see Fig. 9, Plate XIII.), and at the southern end makes a less abrupt junction with a coastal plain. The physiographic evidence, therefore, suggests the existence of powerful transverse faults bounding this region at both its northern and southern ends—the one just to the south of Cairns, the other just to the north of Innisfail.

D. The Innisfail Plain Section.

This is a low plain lying immediately to the south of the region described in Section C (see Fig. 10, Plate XIII.); it extends southwards for a distance of about 18 miles and from the coast inland to the foot of the tableland, a distance of about 20 miles. In its eastern portion where the North Coast Railway line crosses it from Innisfail to Silkwood its altitude is less than 50 feet above sea-level (see Fig. 10). Its western part has not been investigated, but from the railway one gets an uninterrupted view of what appears to be a very low-level

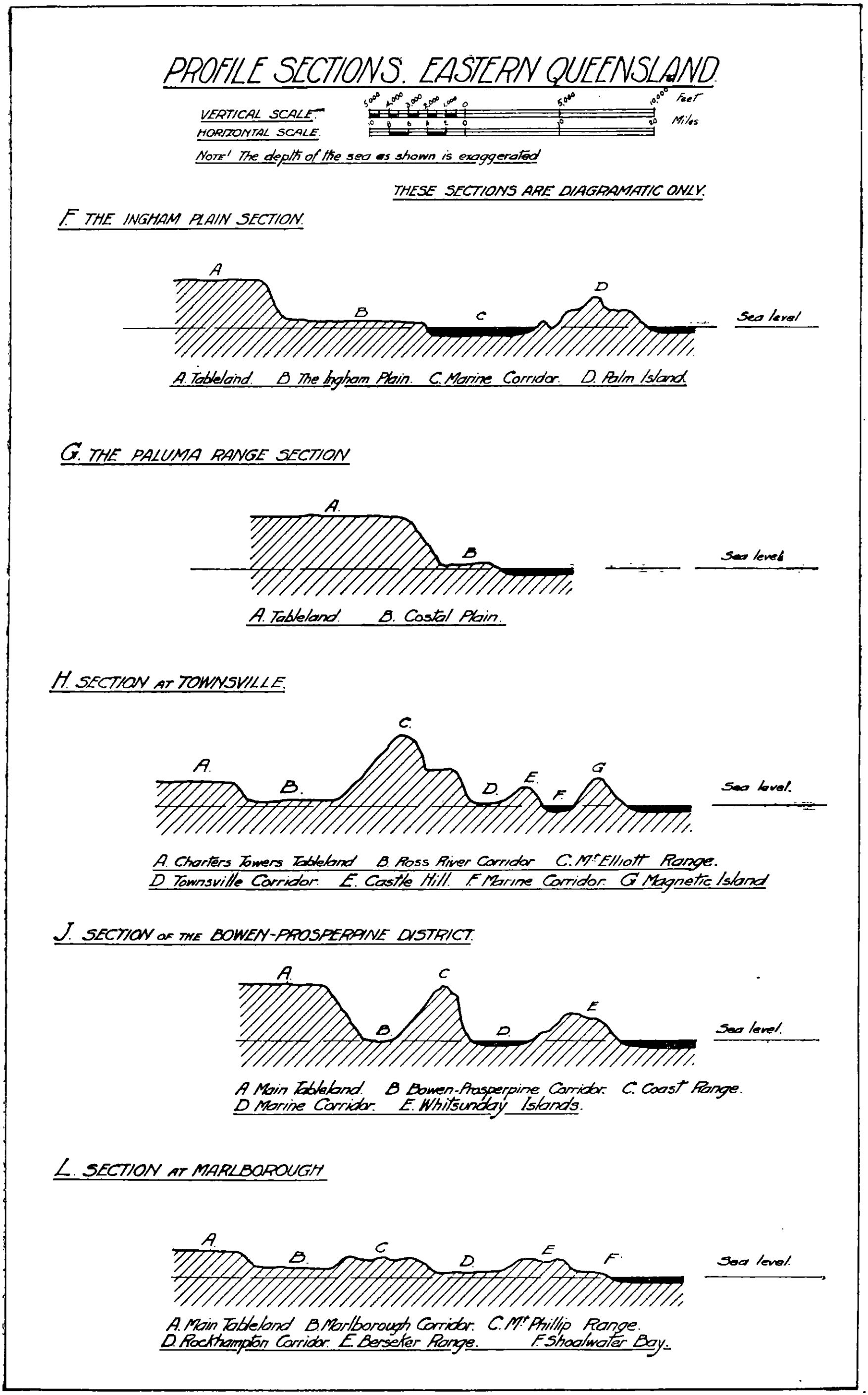

PROFILE SECTIONS. EASTERN QUEENSLAND
VERTICAL SCALE
HORIZONTAL SCALE.
Feet
Miles
NOTE! The depth of the sea as shown is exaggerated
THESE SECTIONS ARE DIAGRAMATIC ONLY.
F. THE INGHAM PLAIN SECTION.
Sea level
A. Tableland B. The Ingham Plain. C. Marine Corridor. D. Palm Island.
G. THE PALUMA RANGE SECTION
Sea level
A. Tableland B. Costal Plain.
H. SECTION AT TOWNSVILLE.
Sea level.
A. Charters Towers Tableland B. Ross River Corridor C. Mt Elliott Range.
D. Townsville Corridor. E. Castle Hill. F. Marine Corridor. G. Magnetic Island
J. SECTION OF THE BOWEN-PROSPERPINE DISTRICT.
Sea level.
A. Main Tableland. B. Bowen-Prosperpine Corridor. C. Coast Range.
D. Marine Corridor. E. Whitsunday Islands.
L. SECTION AT MARLBOROUGH
Sea level.
A. Main Tableland B. Marlborough Corridor. C. Mt Phillip Range.
D. Rockhampton Corridor. E. Berseker Range. F. Shoalwater Bay.

FIG. 2.

surface extending to the foot of the distant tableland. In places, notably near Innisfail, one sees remnants of the late-Tertiary topography, but quite extensive areas are heavily alluviated.

This low-lying region is traversed by three important rivers (Johnstone River, South Johnstone River, and Liverpool Creek) which flow with more or less parallel courses from the tableland to the coast; the divides between these streams are quite inconspicuous.

Still further to the south there occurs a similar extensive low-lying area, which may be referred to as the Tully Plain. It has a length in a north-south direction of about 20 miles and width in an east-west direction of about 12 miles, and is drained by the Tully and Murray Rivers. Along the railway line, which lies at an average distance of about 8 miles from the coast, the altitude does not exceed 50 feet.

Separating the Tully Plain from the Innisfail Plain is a narrow tableland from 6 to 8 miles in width and having an altitude ranging up to 2,500 feet; it is known as the Walter Hill Range, and it extends from the main tableland right to the coast. Immediately opposite its seaward end lies Dunk Island—a continental island some 8 miles in length, 3 miles in width, and ranging up to 890 feet in altitude. The marine channel which separates this island from the mainland has a width of about 3 miles.

E. Section at Hinchinbrook Island.

This section lies immediately to the south of the Tully Plain described above, and is in marked contrast to it; its topography displays three elements—(*a*) The Main Tableland; (*b*) the Hinchinbrook corridor; (*c*) Hinchinbrook Island.

(*a*) The Tableland.—This appears to have a general altitude of about 3,000 feet, and presents a steep, straight scarp along its eastern face. It is here known as the Cardwell Range.

(*b*) Hinchinbrook Corridor.—This has all the features of a typical corridor, having a length of about 20 miles and a width of about 6 miles, but differs in one important respect in that it is divided lengthwise into two sections—a western section, with all the features of typical corridor floor, and an eastern section consisting of a narrow saltwater channel (Hinchinbrook Channel) bordered by extensive mud flats. The western section is drained by a number of short consequent streams which flow directly from the tableland scarp to the Hinchinbrook Channel.

(*c*) Hinchinbrook Island.—This island, apart from the narrow saltwater channel which separates it from the mainland, is in all other respects similar to the various coastal ranges occurring along the Queensland coast. It has a length of about 20 miles, a width of from 8 to 10 miles, and is very lofty, having quite a number of peaks exceeding 3,000 feet in altitude, the highest being Mount Bowen, 3,650 feet high. Hinchinbrook Island ends very abruptly at its southern end, its place

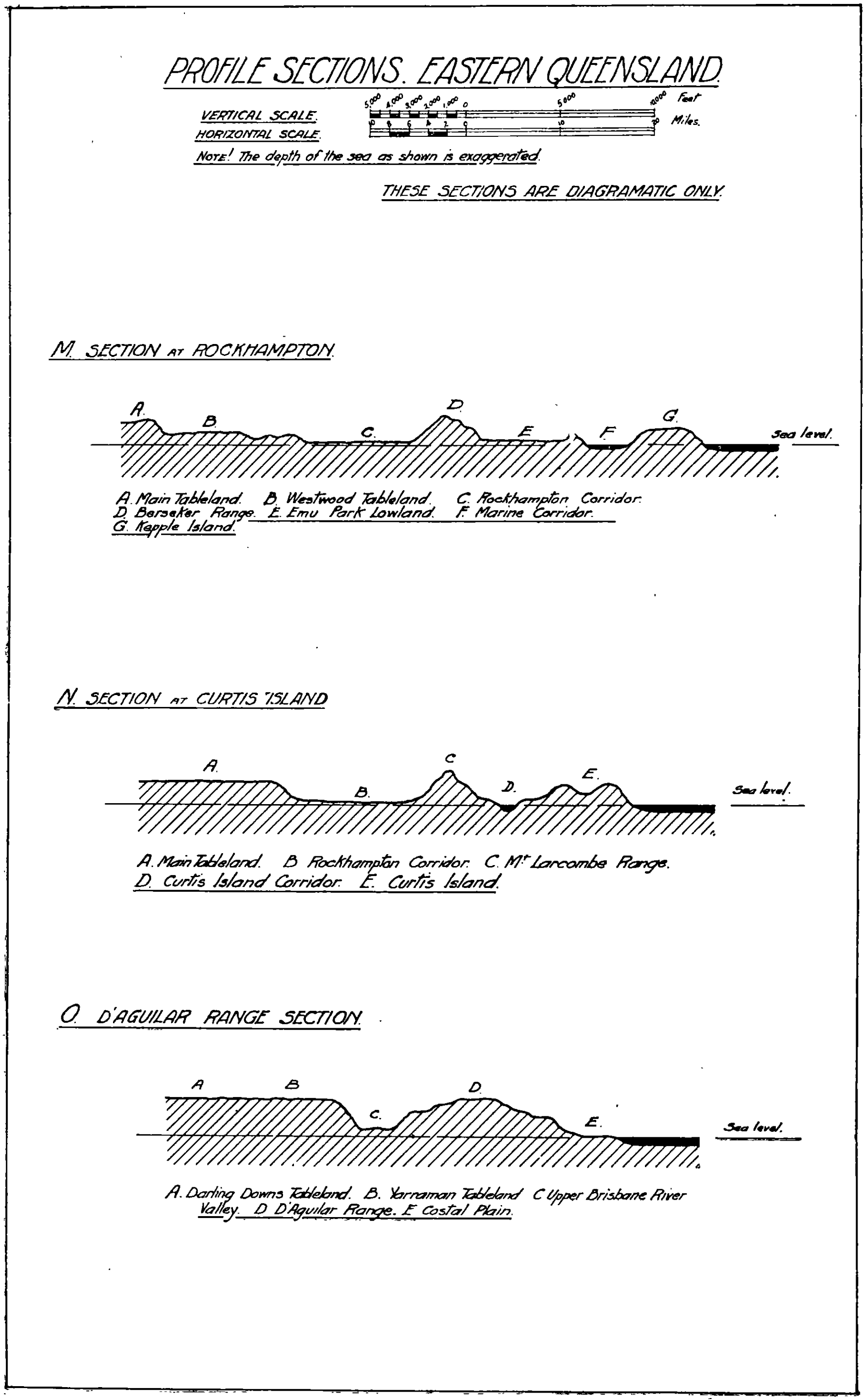

PROFILE SECTIONS. EASTERN QUEENSLAND.
VERTICAL SCALE.
HORIZONTAL SCALE.
Feet
Miles.
NOTE! The depth of the sea as shown is exaggerated.
THESE SECTIONS ARE DIAGRAMATIC ONLY.
M. SECTION AT ROCKHAMPTON.
A. B. C. D. E. F. G.
Sea level.
A. Main Tableland. B. Westwood Tableland. C. Rockhampton Corridor.
D. Berseker Range. E. Emu Park Lowland. F. Marine Corridor.
G. Kepple Island.
N. SECTION AT CURTIS ISLAND
A. B. C. D. E.
Sea level.
A. Main Tableland. B Rockhampton Corridor. C. Mt Larcombe Range.
D. Curtis Island Corridor. E. Curtis Island.
O D'AGUILAR RANGE SECTION.
A B C. D E.
Sea level.
A. Darling Downs Tableland. B. Yarraman Tableland C Upper Brisbane River
Valley. D D'Aguilar Range. E Costal Plain.

FIG. 3.

to the south being taken by swampy flats elevated but little above sea-level; northwards it descends steeply to the ocean.

This island and the adjoining corridor and tableland scarp all have a trend of about N 27° W.

F. Section of the Ingham Plain.

This low-lying area is similar in all respects to the Innisfail and Tully plains already described; it extends southwards from the southern end of Hinchinbrook Island for a distance of about 20 miles, and westwards from the coast for a distance of about 25 miles. The North Coast Railway line traverses it at a distance of from 6 to 10 miles from the coast, and along this line its altitude varies from 50 to 65 feet above sea-level. Parallel to its shoreline, and some 10 to 18 miles distant, is a chain of continental islands known as the Palm Islands, having a length of about 21 miles, and at its southern end (Great Palm Island) having a width of about 10 miles, but tapering to a point at its northern end (North Palm Island); the altitude also is greatest at the southern end (Mount Bentley, 1,818 feet). The marine channel which lies between this chain of islands and the coast has a width of from 10 to 18 miles, and is the widest of the marine corridors.

G. Section—Paluma Range to the Coast.

From Coolbie southwards to Townsville, a distance of about 46 miles, the coast railway traverses a typical coastal plain with an average width of about 5 miles and a general altitude of about 50 feet. The adjoining tableland has a general altitude of about 3,000 feet, and its eastern margin presents a steep, straight scarp; it is known as the Paluma Range. This tableland is drained by streams (tributaries of the Burdekin River) which, rising only a few miles from the sea-coast, flow to the south-west—that is, directly away from the coast. The coastal plain is drained by short consequent streams which flow from the scarp direct to the sea-coast. Scarp, coastal plain, and shore-line all have a trend of N. 47° W.

H. Section at Townsville.

The topography in this region consists of the following elements:—

(*a*) The Main Tableland is known as the Hervey Range in the northern part of the area, and further south is called the Leichhardt Range. This southern part is described by Jardine[16] as follows:—"The Tableland surface on its eastern margin is more or less mature, consisting of a shallowly dissected surface with fairly low, scattered residuals which bound the tableland stream basins." Its general elevation is not much over 1,000 feet.

(*b*) The Ross River Corridor.—This is a low area lying between the tableland, and the Mount Elliott Horst, and varies in width from 12 miles at its south-east end to 8 miles or less at its north-west end; at the latter point it ends abruptly against a high tableland (the Paluma Range, 2,500 feet in altitude). The altitude of the surface of this corridor is given by Jardine as from 150 to 250 feet.[16]

(*c*) The Mount Elliott Range.—This is a wedge-shaped complex mountain block some 25 miles in length, about 10 miles in width at its south-eastern end, tapering to about 4 miles or less at the other end. It has been described in some detail by Jardine,[16] who refers to it as a peculiar group of residuals, and who evidently considered it to be a product of differential erosion. This mountain block is highest at its north-eastern end, where it culminates in Mount Elliott, 3,980 feet high (see Fig. 11, Plate XIV.) ; followed to the north-west, the altitude decreases, and in this portion, known as the Mount Stuart Range, the maximum altitude is 1,921 feet. It is worthy of note that this earth-block, as a whole, greatly exceeds in altitude that part of the main tableland lying parallel to it (Leichhardt Range) ; it is one of the highest mountain blocks in Queensland. At both of its extremities it ends abruptly against coastal plains.

(*d*) The Townsville Corridor.—This lies on the seaward side of the Mount Elliott Range; it has a width of from 3 to 5 miles, and is for the most part very flat and low (see Fig. 11) ; northwards it joins on to and is continuous with the coastal plain described in Section G. This feature has been described in some detail by R. L. Jack, who states that "numerous bores and wells have proved this flat to be composed of alternating beds of clay sand and gravel, the latter being sometimes cemented and consolidated. In the neighbourhood of Townsville a bore through these drifts did not bottom at 125 feet; a bore (Twaddle's No. 2) in portion 100 had 101 feet of drift. As the sites of these bores are not more than 30 feet above sea-level, the rock-head, or old land surface, must be at least 100 feet below present sea-level. No river could possibly have excavated a channel to this depth while the land stood at its present level."

The Townsville Range.—This lies along the coastal side of the Townsville corridor; it is narrow, and has been so much dissected since its uplift that it now consists of three separate sections separated from one another by alluvial flats. The western section is known as the Many Peaks Range, and has a maximum altitude of 721 feet; the central section is the Castle Hill Range, ranging up to 933 feet in altitude; while the eastern section is the Montalunga Range, culminating in Mount Matthews, 1,028 feet high.

(*e*) The Townsville Marine Corridor.—This lies between the shore-line and Magnetic Island, with a width of about 4 miles (see Fig. 12, Plate XIV.) ; to the south-east its place is taken by the alluvial flat which lies between the one-time island of Cape Cleveland and the mainland.

(*f*) The Magnetic Island Chain.—This consists of two elements—(1) Magnetic Island and (2) the one-time island of Cape Cleveland, now rejoined to the mainland by a low, swampy alluvial flat only a few feet above sea-level. Magnetic Island has a maximum width of 6 miles and a maximum altitude of 1,500 feet; the Cape Cleveland mass has a maximum altitude of 2,000 feet. Both have been described in some detail by Jardine.[16]

All of the geographical elements of the Townsville district just described are parallel to one another, and have a trend of about N. 55° W. The rivers which drain this area have, on the other hand, courses which have a trend practically at right angles to this direction.

Section J. The Bowen-Proserpine District.

That part of the coast between Townsville and Mackay has not been visited by the writer, but the Bowen-Proserpine portion of this region has been described in detail by G. A. V. Stanley,[23] and the following details are taken from his description.

In this district, as shown in Section J, there occur the following elements:—

(*a*) The Main Tableland (Clark Range), altitude 2,000-3,000 feet;
(*b*) The Bowen-Proserpine corridor, altitude 50 feet;
(*c*) The Coastal Ranges, altitude 1,500-2,690 feet;
(*d*) The Whitsunday Passage (a marine corridor);
(*e*) The Whitsunday chain of islands, altitude up to 1,426 feet.

This group of elements has a length of about 50 miles and a trend of about N. 45° W. Stanley has published detailed descriptions of all of these, so there is no need to do so here, but his excellent block diagram of the district is reproduced in Fig. 4. It is interesting to note, however, that except for the presence of a chain of continental islands, the features are markedly similar to those described in Sections C and E.

With regard to this region, Stanley arrived at the following conclusions:—

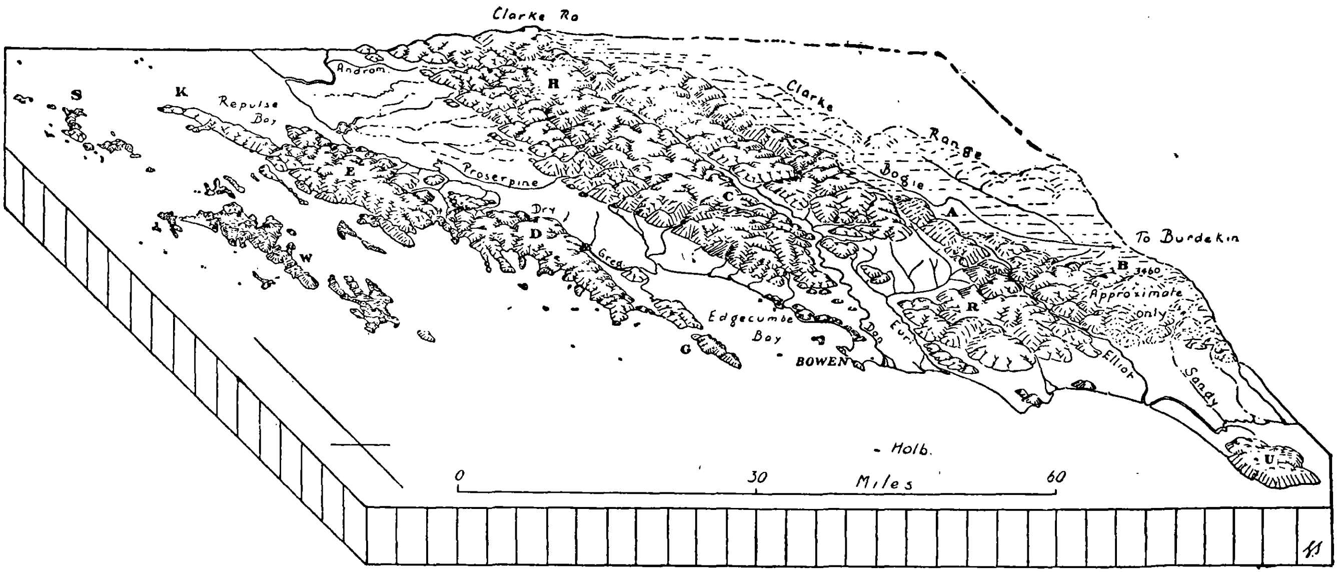
(1) "The systematic arrangements of the physiographic units suggests the operation of a broad control, and suggests that fracturing best explains the observed facts and that morphologically the area consists of a series of fault blocks.

(2) "There is no question of differential erosion; the physiographic units are constituted of many different types of rocks, and they cut across the geological boundaries. In the island festoons both granites and Palæozoic rocks (mostly basic volcanics) figure equally, and the same is true of the coastal ranges."

Section K. Mackay to the Styx River.

This region was only seen by the writer from the train, and the following notes are therefore merely general observations.

As one approaches Mackay from the north the coast railway traverses an extensive lowland with, in places, what appears to be the late-Tertiary topography. South of Mackay this lowland becomes still flatter, but still with occasional low hills to the west; the main tableland lies far to the west. After passing the township of Rosella the railway



Text-fig. 4.—A Block Diagram, showing the salient features of the area investigated. The figure is lettered to correspond with Text-fig. 1. (A) Mt. Aberdeen mass; (B) Mt. Abbott mass; (C) Challenger mass; (D) Dryander mass; (E) Conway Range; (G) Gloucester mass; (H) Composite mass near Mt. Hector; (K) Ranges near Cape Conway; (W, S) Main, or Whitsunday-Shaw Island festoon.

FIG. 4.

runs into a wide corridor with a typical coast-range on its seaward side; the surface of the corridor displays in places what appears to be a typical late-Tertiary topography. The township of Sarina lies in this corridor, near its southern end; it may therefore be referred to as the Sarina corridor. It has a length of about 15 miles.

A few miles south of Sarina the coastal range comes to an end, and the corridor becomes a coastal plain, the surface of which is very flat for the most part, but with occasional low hills. At Tinerta the coastal plain is very flat, and the surface is covered by alluvium, while the adjoining tableland scarp is much dissected. These features continue southwards to Carmila. Still further to the south—at Kalarka—the coastal plain displays a typical late-Tertiary topography, which extends right to the shoreline. The coastal plain just described has a length of about 90 miles, and is only a few miles wide.

A few miles south of Kalarka the tableland margin suddenly falls back westwards for a distance of anything from 10 to 20 miles, giving an extensive flat plain known as the Waverley Plains and similar to those described in Section D. At St. Lawrence it is very flat and heavily alluviated, and its surface is not many feet above sea-level. These conditions continue to Waverley Plains railway station, but from here to the Isis River low rocky hills from 100 to 150 feet in altitude rise above the alluviated surface of the plain, and for some miles the railway line hugs the sides of these hills to avoid the swampy plain. One gets the impression that we have here an original late-Tertiary topography partly drowned in a sea of alluvium.

L. Section from Marlborough to the Coast.

This section is made up of the following elements:—

(*a*) The Main Tableland.—Its eastern face presents a well-marked scarp to the Marlborough corridor.

(*b*) The Marlborough Corridor.—This begins at the Styx River, when its surface is flat and alluviated and only a few feet above sea-level; followed southwards, its surface rises until, at Marlborough, it reaches an altitude of about 400 feet. This corridor has a width of about 8 miles, and its surface presents a typical late-Tertiary topography, the township of Marlborough lying in one of the mature valleys at an altitude of 279 feet. That part of this corridor which lies to the south of Marlborough has not been examined by the writer.

(*c*) The Mount Phillip Range.—This lies between the Marlborough and Rockhampton corridors; it begins at Charon Point, just south of the mouth of the Styx River, and continues from there southwards to the Fitzroy River; it thus has a length of about 36 miles. Its width is from 6 to 10 miles and its altitude ranges up to 1,200 feet, but it has been much dissected since its uplift. The North Coast Railway crosses this feature between Marlborough and Kunwarara—one of the very few places where this railway has to do any climbing.

(*d*) The Rockhampton Corridor.—This will be described in the next section.

(*e*) The Normanby Range.—This is the northern portion of the Berserker Range, which will be described in the next section.

Section M. Section across the Rockhampton District.

The physiography here displays the following elements:—

(*a*) The Main Tableland.—In this district the main tableland is relatively low, having an altitude of about 1,300 feet; its seaward face is everywhere marked by steep scarps.

(*b*) The Westwood Tableland.—This has an altitude of about 600 feet, and is a downfaulted portion of the main tableland; it will be described in some detail later.

(*c*) The Rockhampton Corridor.—This is the largest of all the Queensland corridors; it extends from Broadsound in the north to at least as far south as the latitude of Gladstone, a distance of about 120 miles, while its width varies from 10 to 15 miles. Its surface is not by any means a flat plain, but for the most part displays a typical late-Tertiary topography. This is particularly the case just to the north of Yaamba, where the North Coast Railway has to cross two of the Tertiary ridges—one at Cammoo, and the second at Glen Geddes. The altitude of the surface of this corridor varies from 50 to 120 feet, the Tertiary ridges rising to heights of from 150 to 300 feet above this level. Where present-day rivers, such as the Fitzroy, cross this corridor extensive flood plains have been developed; no rivers run for any distance along its length. At its northern end this corridor dips under the sea at Broadsound.

(*d*) The Coastal Range (Berserker Range).—A continuous coastal range marks the seaward side of the Rockhampton corridor, from Broadsound to the Fitzroy River, a distance of 70 miles; the northern end is known as the Normanby Range, and has a maximum altitude of 800 feet; the southern and main portion is known as the Berserker Range (see Fig. 13, Plate XIV.), and ranges up to 1,300 feet in altitude; its width ranges up to 5 miles. It presents a steep scarp along its western side, and the foot of this scarp coincides, according to Dr. F. Whitehouse, with a strong geological fault separating Carboniferous and Devonian strata. The eastern side of the Berserker Range has the appearance of step-faulting; this, however, needs further investigation.

(*e*) The Emu Park Lowland.—This lies between the Berserker Range and the sea, and has a width of about 14 miles. Its surface is at a similar elevation to that of the Rockhampton corridor, and displays a typical late-Tertiary topography, with an apparently higher range along its seaward margin (the Emu Park and Yeppoon Ranges) which may be a small horst. Followed northwards, this lowland becomes heavily alluviated, and dips under the sea at Shoalwater Bay; it dips similarly but more abruptly under the sea at its southern end at the mouth of the Fitzroy River. An interesting feature of this lowland is the number of Trachytic volcanic necks on its surface, one group occurring along its western margin near its junction with the Berserker Range, with another group lying along its seaward margin.

(*f*) The Keppel Islands Marine Corridor.—This is a marine channel, 8 to 10 miles in width, lying between the coast and the Keppel Island chain.

(*g*) The Keppel Islands Chain.—This is a chain of islands lying parallel to the coast and with a trend of about N. 30° W; these islands have been described in some detail by Jardine.[14]

N. Section at Curtis Island.

This shows the following physiographic elements:—

(*a*) The Main Tableland (Mount Morgan Tableland).—This has an altitude of about 1,300 feet, and presents a straight, steep scarp on its eastern side. Its eastern margin is shown on the land map as the Dee Range.

(*b*) The Rockhampton Corridor.—This is described in the previous section; its southern extremity has not been investigated. Its width here is about 20 miles.

(*c*) The Coastal Range.—At its northern end (just south of the mouth of the Fitzroy it is known as the Rundle Range and has a maximum altitude of 800 feet; at its southern end it is known as the Mount Larcombe Range, culminating in Mount Larcombe, 2,060 feet in altitude. The North Coast Railway crosses through this range just after leaving Gladstone, going north.

(*d*) The Curtis Island Corridor.—This is similar to the Hinchinbrook Island corridor already described, and has a width of from 4 to 5 miles.

(*e*) Curtis Island.—This island (including Facing Island at its southern end) has a length of about 35 miles and a width varying from 4 to 12 miles. Its altitude is low, the highest point being Ship Hill (600 feet). It has been described in detail by Jardine.[14]

O. South-Eastern Queensland (D'Aguilar Range Section).

The geomorphology of this district has already been described by the writer in a previous paper,[24] in which a series of highlands and lowlands was described similar in all their essential features to those occurring in the regions described in the present paper, and the view was expressed that the main control in the production of the land-forms there was differential uplift accompanied by block-faulting and warping.

V. Summary of the Physiographical Features.

From the descriptions given of the various sections of Eastern Queensland it will be seen that the physiographic features may be classified as follows:—

A. The relatively Uplifted Blocks—
- (*a*) The Tablelands.
- (*b*) The Coastal Ranges.
- (*c*) The Chains of Continental Islands.

B. The Relatively Depressed Blocks—
- (*d*) The Corridors.
- (*e*) The Coastal Plains.
- (*f*) The Broad Lowland Areas.
- (*g*) The Marine Corridors (Marine Channels).
- (*h*) The Continental Shelf.

The block diagram of the Bowen District in Fig. 4 gives an excellent representation of most of these features, and shows particularly their relation to one another.

(*a*) *The Tablelands.*—These have been already described in a previous section.

(*b*) *The Coastal Ranges.*—Those which have been described are listed in the following table:—

Table I.—The Coastal Ranges.

Name.	Length in Miles.	Width in Miles.	Altitude (in feet).	Trend.
1. The Malbon–Thompson and Graham Ranges	44	4	1000–3317	N 30° W.
2. Hinchinbrook Island	20	8–10	3000–3600	N 27° W.
3. Mount Elliott Ranges	25	4–10	2000–3980	N 55° W.
4. Tower Hill Ranges	20	1	700–1025	N 55° W.
5. The Dryander–Conway Ranges	50	8–10	1500–2690	N 45° W.
6. The Mount Phillips Range ..	64	8	1000–1200	N 30° W.
7. The Normanby–Berseker Ranges	70	5	up to 1300	N 30° W.
8. The Rundle–Mount Larcombe Ranges	30	4–5	800–2000	N 30° W.
9. Curtis Island	33	8–12	Up to 600	N 30° W.
10. The D'Aguilar Ranges	30	14	2000–2200	..

Hinchinbrook Island and Curtis Island are included here because, although they are technically islands, the corridors which connect them with the mainland differ from other corridors merely in the presence of a narrow saltwater channel along one side, the remainder of the corridor being dry land.

These coastal ranges are similar to one another in all their essential features, differing only in their size; they range from 20 to 70 miles in length and from 1 to 14 miles in width; the wider ones, such as Hinchinbrook Island and the D'Aguilar Range, are tableland blocks differing in no essential features from the neighbouring tablelands. A comparison of the altitude of the coastal ranges with the nearest tableland in each case shows no regular relation between the two—in some cases it is approximately the same; in other cases the coastal range is higher than the tableland; while in still other cases it is markedly lower. All of these coast ranges present steep, straight scarps to the lowlands on either side, while in many cases they terminate quite abruptly at one or even at both ends (see Fig. 4).

In all cases they, in common with the neighbouring tablelands, have suffered considerable dissection, but this dissection is for the most part still in the early mature stage, giving a quite youthful topography, which is in marked contrast with the thoroughly mature or even old-age topography of the adjoining lowlands, the junction between the two being always markedly abrupt.

(*c*) *The Chains of Continental Islands.*—Those of the Whitsunday group have been described in full detail by Stanley,[23] while those of the Keppel Island group have been similarly described by Jardine.[14] With regard to their length and width, they closely resemble the Coastal Ranges, but, of course, are more disconnected along their length. Their altitude is considerable, but is in most cases lower than that of the nearby coastal ranges and tablelands. A rise of sea-level of a few hundred feet, or a similar subsidence of the land, would convert most of the coastal ranges into similar chains of islands.

(*d*) *The Corridors.*—Those which have been described are listed in the following table:—

TABLE II.—THE CORRIDORS.

Name.	Length in Miles.	Width in Miles.	Altitude of surface in feet.	Trend.
1. The Mulgrave River Corridor ..	44	4	25–50	N 30°W.
2. The Hinchinbrook Island Corridor	20	6	150–50	N 27° W.
3. The Ross River Corridor ..	30	8–12	150–250	N 55° W.
4. The Townsville Corridor ..	30	3–5	25–50	N 55° W.
5. The Bowen–Proserpine Corridor	40	5–7	25–50	N 45° W.
6. The Sarina Corridor	15	..	50	..
7. The Marlborough Corridor ..	40	8	50–300	N 30° W.
8. The Rockhampton Corridor ..	110–120	12/15	50–120	N 30° W.
9. The Curtis Island Corridor ..	33	4	25–50	N 30° W.
10. The Upper Brisbane River Corridor	30	4–6	400	..

It will be seen that they vary from 15 to upwards of 100 miles in length and from 3 to 15 miles in width. The nature of their surfaces vary; some are almost quite flat, and such are covered with alluvium of varying thickness; others display what the author considers to be a typical late-Tertiary topography, such as has been described in connection with the tableland surfaces; while on still others one finds a similar late-Tertiary topography, but partly drowned in a sea of alluvium. The altitude above sea-level of the different corridors also varies, ranging from less than 50 feet up to 400 feet; in at least two cases the original rock surface of the underlying earth-block is upwards of 100 feet below sea-level; in these cases it is only the alluvium cover which rises above sea-level. In some examples the surface is tilted lengthwise, in consequence of which one end may dip below sea-level; others, again, appear to have a coastwise tilt. In the example shown in Fig. 4 it will be seen that it disappears under the sea at its northern end, and that southwards it continues as a coastal plain.

(*e*) *The Coastal Plains.*—These closely resemble the corridors in all their essential features, except for the absence of a coastal range on their seaward side. In some cases they join up with corridors at one or both ends. Their width varies from 2 to 6 miles, and their length ranges up to 70 miles or more.

(*f*) *The Broad Lowland Areas.*—These have been referred to by previous writers as coastal plains; they differ from them only in their greater width and the fact that they are bounded by tablelands on three sides instead of one. They have no coastal ranges on their seaward side. The junctions of their relatively flat surfaces with the tableland scarps is always abrupt. Each of the broad lowland areas described here is drained by two or more important streams, which flow out on to their surfaces from the adjoining tablelands, traversing them with decidedly meandering courses. The divides between these streams where they traverse these lowland areas are quite inconspicuous.

Such lowland areas are considered to be portion of the Tertiary land surface which lagged behind during the uplift which produced the adjoining tablelands. They may therefore be referred to as "stillstand" areas.

(*g*) *The Marine Corridors.*—These are the sea channels which lie between the chains of islands and the mainland. Such channels vary from a few miles up to 18 miles in width, and their only essential difference from the dry-land corridors is that they are covered by the sea.

VI. Origin of the Physiographical Features.

The descriptions already given show that throughout Eastern Queensland, from Cairns to the southern border, the physiographic features can be grouped into a number of definite units which are parallel to one another and parallel to the existing shore-line (see Fig. 4); this consistent systematic arrangement suggests the operation of one broad control throughout this region during late-Tertiary and Post-Tertiary time. Previous observers have expressed two entirely different views as to the nature of this control; some have suggested the control to be differential erosion following the general strike of the sedimentary formations, while others, including the writer, support the view that differential uplift, accompanied by block-faulting, has been the dominant factor in producing the present topography. The former view will be discussed first.

The trends of the physiographic units occurring in the various districts are listed in Tables I. and II. It will be seen that these trends vary from N. 27° W. to N. 55° W. The strikes of the various sedimentary formations occurring in the same districts vary from N. 20° W. to N. 45° W. (there are, however, many departures from this generalization), and there would thus at first sight appear to be a general accordance between the two. When individual districts are examined, however, it is found, in most cases, that such accordance is more apparent than real, as has been pointed out by Stanley for the Bowen district. Associated with the sedimentary strata over much of Eastern Queensland are numerous granite bathyliths of the subsequent type whose boundaries, for the most part, do not parallel the strike of the invaded formations; the trends of the physiographic units cut across such boundaries in many places and traverse the igneous and sedimentary rocks quite indifferently, and in some localities even cut across the strike of the sedimentary formations themselves. In some localities, also, the geological formations underlying the lowlands are identical with those occurring in the adjoining higher blocks. If one studies the geological map of the area occupied by the Rockhampton corridor these facts will be at once apparent. Under the above conditions differential erosion is a quite inadequate explanation of the existing physiographical features.

Further, had the corridors been produced by differential erosion during the present cycle, one would expect to find a close association of the larger streams with them; such an association is the exception, and most of the larger streams have their courses more or less at right angles to the trends of the corridors, the latter being drained by unimportant streams with quite limited catchment areas; such streams appear to be quite incapable of having produced such wide flat valleys during the time that much larger streams in the nearby tablelands had produced relatively youthful valleys.

Had the corridors been produced by erosion during the existing cycle, there should be a definite and regular relation of their surfaces to the base level of erosion, which in all these cases is sea-level; but no such regular relation exists. In the cases of at least two of the corridors their original rock surfaces are upwards of 100 feet below sea-level, while others have their surfaces well above sea-level and at varying elevations. In the Rockhampton district there are two parallel corridors one with its surface nearly 300 feet higher than the other.

Reference has been made to the typical late-Tertiary topography which exists on the surfaces of some of these corridors, similar in every respect to that which occurs on parts of the tableland surfaces, and it has been shown that such a topography requires more than one cycle of erosion for its development; yet one finds it occurring side by side with the youthful topography of the adjoining higher blocks.

From the evidence one must conclude that differential erosion cannot adequately explain the origin of the physiographical features

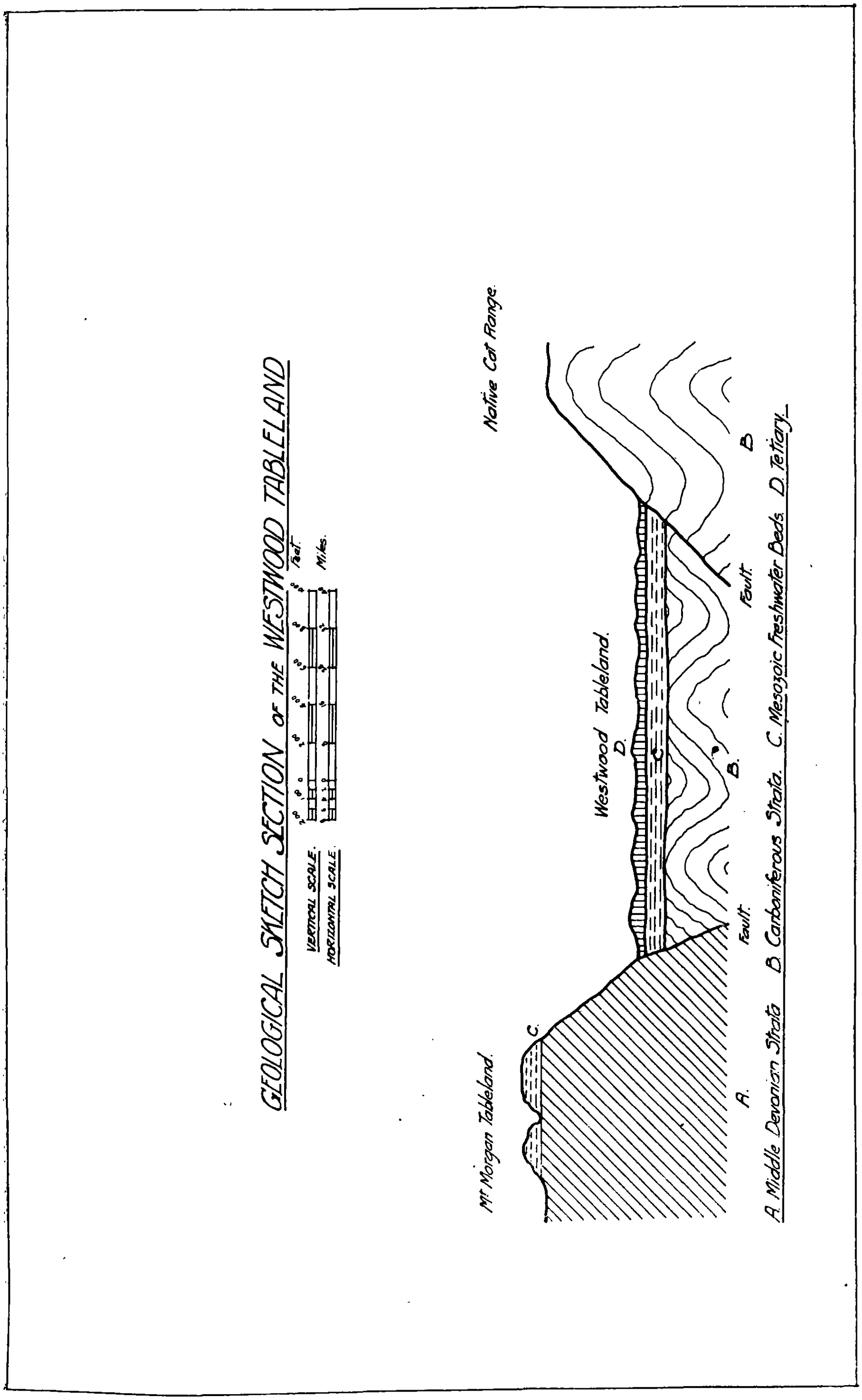

GEOLOGICAL SKETCH SECTION OF THE WESTWOOD TABLELAND
VERTICAL SCALE
HORIZONTAL SCALE
Feet
Miles
Mt Morgan Tableland
Westwood Tableland
Native Cat Range
Fault
A. Middle Devonian Strata B. Carboniferous Strata. C. Mesozoic Freshwater Beds. D. Tetiary.

FIG. 5.

of Eastern Queensland, and consideration will now be given to the evidence in favour of block-faulting.

The main tableland is everywhere, on its seaward side, bounded by steep, straight escarpments, while similar scarps bound the coastal ranges on both sides. The salient features of these scarps may be summarised as follows:—(1) They have straight or gently curved courses for long distances; (2) they display a youthful topography as compared with the very mature topography of the lowlands which occur at their bases; (3) no spurs extend out from them on to the adjoining lowlands; (4) in most examples they cut indifferently across the trends and boundaries of the geological formations traversed by them. These features are all such as characterise fault scarps.

Besides this physiographic evidence, there is also available, in a number of cases, geological evidence of faulting; in his description of the geomorphology of the Moreton district,[24] in South-Eastern Queensland, the writer has drawn attention to the definite geological evidence for the presence of important faults coinciding with the position of some of the scarps of that district.* In the Rockhampton district, also, evidence is available that some of the scarps coincide in position with important geological faults. In Fig. 5 is given a diagrammatic geological section along an approximate north-west, south-east line of the region occurring immediately to the west of the Rockhampton corridor at Rockhampton. It will be seen that the Mount Morgan Tableland, which here has an altitude of about 1,300 feet, consists of highly folded Middle Devonian strata (with some associated granites), capped in places by nearly horizontal freshwater strata of Mesozoic age. The adjoining Westwood Tableland, which is much lower, with an average altitude of about 600 feet, consists of folded Carboniferous strata capped with gently undulating Mesozoic freshwater strata, and these, in turn, capped over part of the area by Tertiary basalts. It is obvious that an important line of faulting must be present here between the two regions; and the geological mapping of the district indicates that its position probably coincides with the foot of the scarp which separates the two tablelands, as shown in the section. The line of faulting along the northern margin of the Westwood Tableland has been mapped by J. H. Reid and C. Morton, and the writer has been informed by J. H. Reid that the position of the fault corresponds with the foot of the scarp on that side. These two scarps are transverse to the strike of the sedimentary formation. On the western side, also, the Westwood Tableland is bounded by a scarp which corresponds in position with a faulted junction between Lower Palæozoic basic igneous rocks and the younger strata of the Westwood Tableland. Along its eastern side the Westwood Tableland overlooks the lower Rockhampton corridor, a much-dissected scarp occurring along the junction. This is probably

* EDITOR'S NOTE.—It should be pointed out that portion at least of this faulting has been demonstrated to be pre-Tertiary by W. E. Cameron, who mapped it as such (Geol. Sur. Qld., Publ. No. 271, 1923).

also a fault scarp, but the writer cannot quote any geological evidence in support of the faulting. There is thus definite geological evidence that at least three of the scarps which bound the Westwood Tableland are associated with lines of faulting. In the Rockhampton district there is another well-marked scarp occurring along the western side of the Berserker Range. The writer has been informed by Dr. F. Whitehouse that a well-marked line of faulting occurs along the foot of this scarp, lying between Devonian and Carboniferous strata. Along the eastern side of this range there appears to be a faulted junction between Devonian strata and an older series of schists, &c. L. C. Ball[4] has described the Many Peaks Range, in the Gladstone district, as being a granite horst, and has given geological evidence in support of the faulting.

In most parts of Eastern Queensland very little detailed geological mapping has been carried out; consequently, definite geological proof of faulting is not available for many of the supposed fault scarps. These particular scarps are, however, so similar in their physiographical features to those for which geological proof is available that it is quite reasonable to assume that all of them have had a similar origin.

The tectonic scarps of Eastern Queensland may be divided into two groups—(*a*) Those approximately parallel to the dominant trends (N. 29° W. to N. 55° W.), and (*b*) those transverse to these trends. The former may, for convenience, be referred to as the longitudinal scarps, and the latter as the transverse scarps. Both groups of scarps display a similar amount of dissection, an indication that they have been developed more or less simultaneously. With regard to the transverse scarps, there is, in the writer's opinion, little doubt as to the faulting, because their trends cut right across the strike of the sedimentary formations. Differential erosion can hardly be argued as a reason for their development. The writer has been able to examine only two of these in detail—both in the Rockhampton district—and in both the physiographic evidence is supported by geological evidence.

The effect of these suggested transverse faults upon the geomorphology is very striking, particularly the way in which they bring about an apparent alternating approach and retreat of the tablelands to and from the shore-line. This is well shown by the sections C and E in Fig. 1, and the sections H and I in Fig. 2 We have in each case a similar complex group of highlands (including also, a corridor,) extending right to the shore-line, while lying between these highland blocks are the great flat lowland areas behind which the tableland margin is from 20 to 25 miles back from the shore-line. The change from the highland blocks to the lowland blocks is quite abrupt. This is particularly the case at the southern end of the Bellenden-Ker highland block, where it ends with quite dramatic suddenness against the Innisfail plain.

This feature is also well shown in G. A. V. Stanley's block diagram of the Bowen district (Fig. 4), which shows a complete series of physiographic elements—namely, tableland, corridor, coastal range, marine corridor, and a chain of islands, all coming to an abrupt end at their northern extremities, and the whole coast stepped back towards the west.

Taking into consideration the whole of the evidence available, the writer is of opinion that all of these scarps are fault scarps. It may be that some of the scarps are due to warping rather than faulting, but this would not alter the fact that they are tectonic scarps and not erosional scarps. If this conclusion is correct, then the coast-ranges and chains of continental islands are fault blocks, the corridors, both land and marine, are rift-valleys, while the coastal plains and broad lowland regions are still-stand areas—that is, parts of the late-Tertiary land surface which lagged behind during the general uplift.

E. C. Andrews,[3] in that part of his discussion on the origin of mountain ranges which deals with Australia, makes the following statement:—"High sub-parallel, but broken and interrupted ranges occur between the main highlands and the coast in places, as in Victoria, and are separated from the main highlands by broad and low-lying structural valleys. In Queensland this feature is indicated, also, by the alignment of certain island groups, of marine passages on the continental shelf, by coastal ranges and the valleys between them and the more inland main irregular tablelands or highlands."

It is obvious that E. C. Andrews considered that the coast ranges and the chains of continental islands have had a structural origin.

Differential erosion has, however, played quite an important part in modifying the uplands during and subsequent to their uplift. This is notably the case, for example, in the Townsville district. Here the rocks are dominantly granites, but associated with these are relatively small areas of Permian volcanic rocks which have yielded to denudation more readily than the granite has, and as a result the horsts have been practically cut through in a number of places by transverse valleys. Similar conditions have been described by G. A. V. Stanley for the Bowen district.

VII. The Kosciusko Uplift.

The great crustal movement which produced the existing tablelands of Eastern Australia has been named by E. C. Andrews[2] the "Kosciusko Uplift," and was considered by him to have taken place at the close of the Tertiary period. The area affected extends from Tasmania to North Queensland, and has a width ranging up to 300 miles or more. Its long axis has a general meridional trend, but with a marked convexity towards the Pacific Ocean. Along this main axis the amount of uplift varied, being only a few hundred feet in some places, but ranging up to 6,000 feet in the Kosciusko Tableland of New South Wales and up to 5,000 feet in the Bellenden-Ker Range of Queensland. This unequal uplift is considered by the writer to have developed strains transverse to the main axis as the uplift progressed, and it is considered that such strains were relieved in places by the development of transverse faults and warps such as have been suggested. The movement of uplift is also considered to have been a differential one along lines transverse to the main axis, the tendency of the uplift being to produce a broad, arched surface with a warp towards the coast on the one hand and a corresponding warp towards the inland plains on the other hand. This differential movement tended to produce a second set of strains along lines parallel to the main axis of uplift, and these were relieved by the production of lines of faulting and monoclinal folding. As both sets of strains developed more or less simultaneously, so both the transverse and longitudinal faults and warps were developed simultaneously as the uplift progressed, with the result that the tablelands as they developed were divided into a series of rectangular blocks (fault-blocks) of differing elevation; along what is now the coastline of Queensland there were elevated a number of relatively long and narrow fault-blocks, or horsts, and between these and the main tableland rift valleys were simultaneously developed.

The development of the suggested transverse faults has produced a curious alternation of highland and lowland regions in Eastern Queensland, and with this is associated the repeated stepping-back of the shoreline towards the west as one follows it northwards. A similar set of transverse and longitudinal fractures has been described by Richards and Hedley along that part of the coast extending from Cooktown to Cape York, with a similar stepping-back of the coast.

VIII. The Continental Shelf.

Consideration may now be given to the continental shelf and its probable origin. This feature has already been described in some detail by W. H. Bryan and other writers, so that only brief reference to certain of its features is necessary here. Its width varies from 15 miles to 160 miles, being widest where the adjoining tablelands are also widest. The surface of the shelf as it exists to-day is, in general, fairly flat, averaging about 200 feet in depth below sea-level. There are, however, certain areas which are notably deeper, and such deeper areas have linear trends which parallel in general the main physiographic features. A notable case is that of the Capricornian Channel, together with an elongate depression in about latitude 20° S., with which it is in line. In both the depth exceeds 35 fathoms. Another example is the Whitsunday Passage, which in places reaches a depth of 50 fathoms. G. A. V. Stanley has drawn attention to the striking alternation of island arcs and submarine deeps in this region.[23] A very striking feature of the continental shelf in Queensland is the occurrence of chains of high continental islands along its western margin close to and parallel to the shoreline. It will be seen that the alternation of what the writer considers to be rift valleys and horsts which characterises the margin of the land has its counterpart in the marine corridors and chains of islands on the inner surface of the continental shelf, and this suggests that a similar control has operated in their formation in both cases, and further suggests that the uplift which produced the tablelands was accompanied by a down-warping which produced the continental shelf, as has been suggested by E. C. Andrews.

If the continental shelf is a portion of the Tertiary land surface which subsided at the close of Tertiary time, what was the extent of the subsidence? The present depth of the water which covers it does not afford a reliable measure, because there is no doubt that extensive sedimentation has taken place on its surface since the subsidence began. Very valuable evidence on this point has been supplied by the borehole put down by the Barrier Reef Committee[21] on Michaelmas Reef some few years ago. This borehole was carried down to a depth of 600 feet without reaching the original surface of the shelf, and passed through the following sediments:—

0- 12 feet—Coral dune sand of the beach.
12- 19 feet—Solid coral (Porites).
19- 21 feet—Broken coral (Pocillopora).
21-427 feet—Coralline material (loosely coherent).
427-600 feet—Quartz sand with abundant Foraminifera and shell fragments and much glauconitic material.

There is no reason for supposing that this thickness of sediments is abnormal for the continental shelf as a whole, and the evidence therefore suggests a probable subsidence of at least 600 feet. It would be more conclusive, of course, if similar evidence were available from at least two more widely-spaced boreholes.*

It seems reasonable to suppose that at the beginning of the Pleistocene period—that is, before the advent of the great Ice Age—the sea-level was not appreciably lower than it is to-day; in fact, it may even have been higher, because there is still enough water locked up in the form of ice on the earth's surface at the present time, according to R. A. Daly's estimate, to produce a rise of sea-level of about 100 feet if it were all to be melted and added to the ocean basins. It is true that during the epoch of maximum glaciation the sea-level may have been anything from 200 to 240 feet lower than it is to-day, but this lowering of sea-level was only temporary, repeated, perhaps, several times, but followed by a rise in sea-level during each of the interglacial epochs. One of these interglacial epochs continued for so long a period of time that during its continuation sea-level was probably at least as high as it is to-day. Even allowing for such temporary lowering of sea-level as may have taken place at intervals during the Pleistocene period, the apparent great depth of the surface of the continental shelf below sea-level, as revealed by the Michaelmas Island bore, makes it practically impossible that marine erosion could have been the main control in its production. On the contrary, the evidence suggests that the continental shelf was produced by a subsidence of the land at the close of Tertiary time, the subsidence being accompanied by

* Since the above was written, a second borehole has been drilled to a depth of 732 feet near the southern end of the Barrier Reef area, and this has revealed an almost exactly similar series of sediments, and has also not reached bedrock.

sedimentation. Some modification by marine erosion may have taken place in the early stages of the subsidence, but this must have been quite a subordinate feature.

IX. Conclusions.

As a result of this study, the following conclusions have been arrived at:—

1. The geomorphology of Eastern Queensland has been developed primarily as the result of differential crustal movements accompanied by block-faulting and probably also by some warping.
2. The coast-ranges and chains of continental islands are fault blocks (horsts).
3. The corridors—both land and marine—are rift-valleys.
4. The coastal plains and broad lowland areas are still-stand areas—that is, areas which lagged behind during the general uplift.
5. Differential erosion has played an important part in the dissection of the tablelands and horsts since their uplift.
6. The continental shelf is a part of the Tertiary land surface which subsided beneath the sea simultaneously with the uplift of the tablelands, the subsidence being accompanied by some block-faulting and warping.
7. Accompanying and following the subsidence, extensive sedimentation has taken place on the continental shelf.

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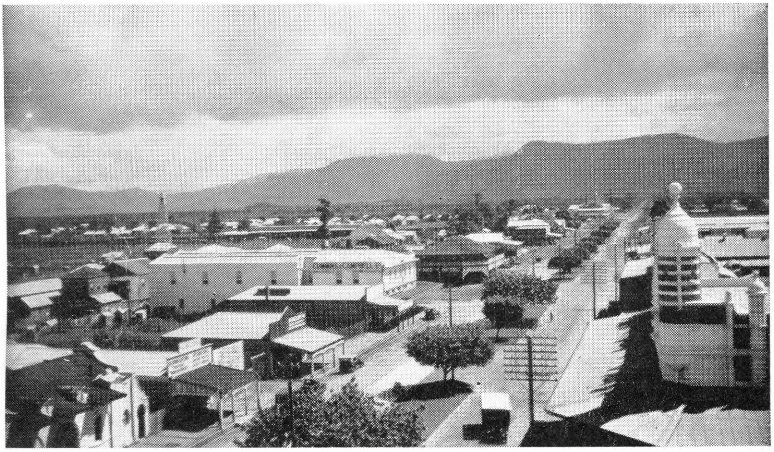

FIG. 6.
Coastal Plain at Cairns, looking towards the Tableland Scarp.

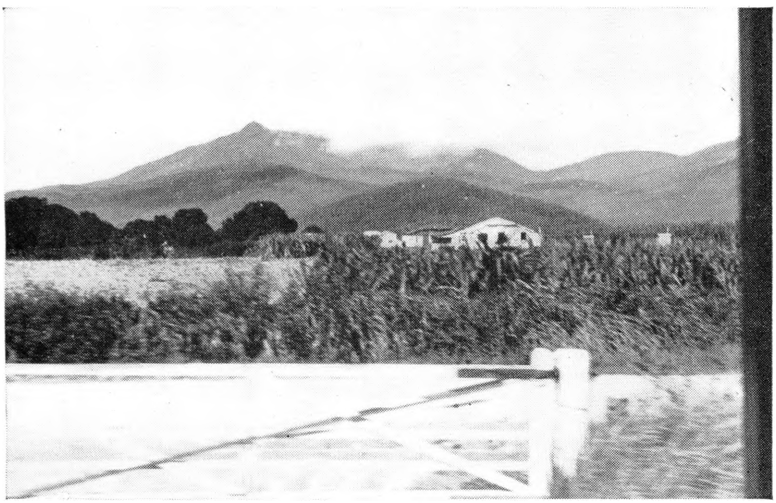

FIG. 7.
The Mulgrave River Corridor, looking towards the Bellenden-Ker Range.

FIG. 8.
Transverse Scarp at the southern end of the Bellenden-Ker Range, with the Innisfail Plain in the foreground.

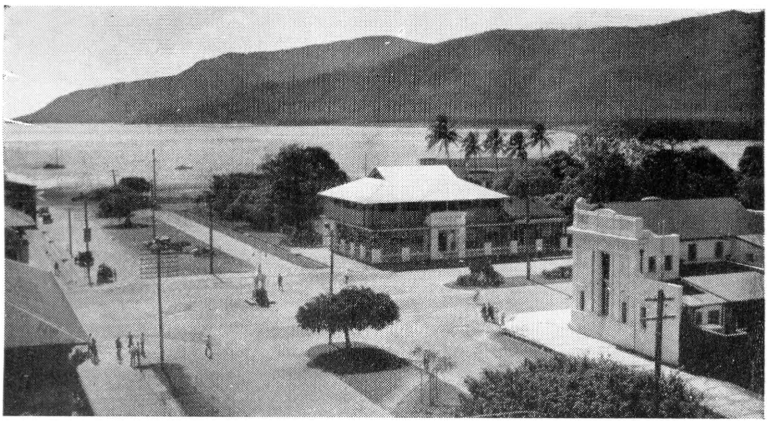

FIG. 9.
The northern end of the Malbon-Thompson Range where it ends abruptly at the ocean, as seen from Cairns.

FIG. 10.
The Innisfail Plain.

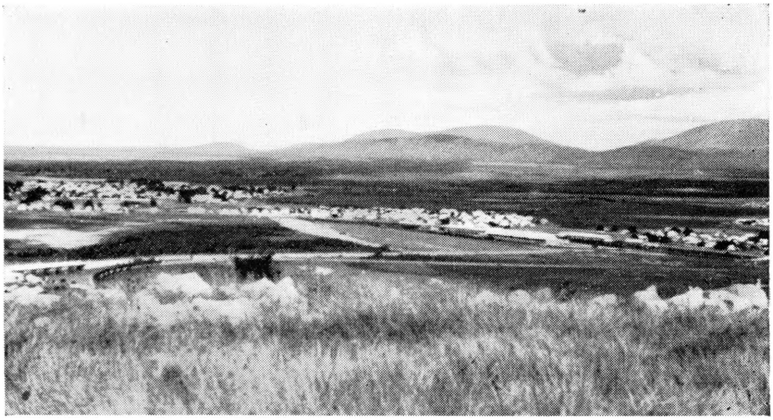

FIG. 11.

View from Castle Hill, Townsville, looking across the Townsville Corridor, towards the south-eastern end of Mount Elliott.

FIG. 12.

The Marine Corridor at Townsville.

FIG. 13.

View of the Western Scarp of the Berserker Range at Rockhampton, with part of the Rockhampton Corridor in the foreground.

No. 9.

BORING OPERATIONS AT HERON ISLAND, GREAT BARRIER REEF.

(17th May to 13th August, 1937.)

By PROFESSOR H. C. RICHARDS, D.Sc., Chairman, Great Barrier Reef Committee.

(Plate XV.)

Following upon the boring operations of 1927 at Michaelmas Cay (Lat. 16° 36′ S., Long. 145° 59′ E.) the Great Barrier Reef Committee has had in mind constantly the desirability of putting down further bores in other portions of the "reef." As the first bore was placed approximately midway along its length the two places given most consideration have been the northern and the southern regions. Owing to practical difficulties, not yet overcome, of finding a suitable station which is not too far from a base the northern proposal necessarily gave place to that in the southern end.

At all times the Committee has desired to have its boring sites located as near as possible to the line of the "outer barrier." The Michaelmas Cay bore was 10 miles from the edge and was as near thereto as it was feasible to set up a station, while in the case of the southern proposal this requirement has been kept constantly in mind.

Few people unacquainted with the Barrier Reef regions appreciate the difficulties associated with the location of the bore sites. Briefly the requirements of a suitable site may be enumerated as:—

(i.) The presence of a sufficient area permanently above the level of high water spring tides to enable the erection of the plant and the camp establishment.

(ii.) Reasonable depths of water in the way of an approach for landing and taking off the gear which in the aggregate may reach 30 tons, with individual items, such as the engine or winch, reaching as much as 3 tons each.

(iii.) A fresh water supply.

(iv.) A base placed reasonably for obtaining supplies of food, gear, &c.

(v.) The maintenance of communication with the base.

Time and again the Committee has been asked why boring operations have not been carried out on the "Outer Barrier" itself. The answer is that we do not know of any place along the whole 1,200 miles length of the "reef" where the above conditions hold.

If the Admiralty Chart No. 345 be consulted, Heron Island (Lat. 23° 26′ S., Long. 151° 57′ E.) may be located some 10 miles from the 100 fathom line and approximately 44 miles from the mainland. The 100 fathom line must be taken as indicating the outer edge of the "reef" in these waters where there is much indefiniteness about the continuity of the outer edge.

The Heron Island reef-patch which is elongated in an E.-W. direction is 7 miles long and 2 miles wide. The Sand Cay, which is heavily vegetated, is situated on the western extremity and is approximately 1 mile in circumference; the western edge of this just above high-water mark was the location of the bore-site. The actual level of the borehole was 18 inches above the highest spring-tide level.

While there are many other reef-patches in this area and Wistari reef is closely adjacent to the south-west, the water in the channels around Heron Island reaches a depth of 27 fathoms and on the whole is reasonably deep to within a few hundred feet of the bore site.

The experiences of the Committee at the Michaelmas Cay boring were kept well in mind in the selection of this new site and the presence of an adequate supply of fresh water, of a permanent camp, of a regular boat communication with Gladstone some 48 miles away, and a good depth of water so near a suitable bore-site were all factors of very considerable practical and economic importance.

By arrangement with Captain C. Poulsen of the Barrier Reef Tours Ltd. satisfactory messing and accommodation requirements were soon established, while a weekly boat to Gladstone guaranteed regular communication for personal transport, mails, and supplies.

Several other islands in the Bunker and Capricorn Groups of Coral Cays would have met our requirements as far as a suitable cay on which to bore, but no other offered any of the several other advantages given by the choice of Heron Island because they are uninhabited, have no supplies of fresh water and no established connection with a base for mails, transport, supplies, &c.

Moreover Heron Island is at least equal to the best of any of these other islands on a purely physical basis of selection, so that in every way the Committee felt content about its selection as the base of operations.

As on the previous boring occasion we were not able to obtain from the Queensland Government a boring-plant, so an approach was made to the Victorian Government. This request of the Committee was met on most generous terms and the Minister for Mines expressed a desire to do what was possible in helping the Committee.

A very suitable "Victoria" drilling plant was loaned, adjustable for both percussion and rotary drilling operations. The Committee defrayed the expense of having it conditioned and transported, and also undertook to employ a crew of four men who were accustomed to the working of the plant. We were fortunate in obtaining again the services of Thomas Hughes, who had been the foreman at Michaelmas Cay boring.

The Minister for Mines (Hon. J. Hogan, M.L.A.) in addition graciously allowed Mr. J. Binney, the Victorian Engineer for Boring, to supervise the whole of the boring operations. This involved two visits of Mr. Binney from Melbourne to Heron Island.

For the generous help and highly-skilled supervision at no cost to the Committee for salary and transport, also for the loan of the plant without cost, the Committee is much indebted to the Mines Department of Victoria.

The Government of Queensland was also more than generous in meeting all railway transport charges in Queensland for men and materials. These were of the order of several hundreds of pounds, due largely to rail transport of gear between Brisbane and Gladstone.

To the Commonwealth Lighthouse Service also we are very specially indebted. The transport both ways between Gladstone and Heron Island of our boring gear by the lighthouse steamer "Cape Leeuwin," through the courtesy of Captain Clinch and his officers, was of the greatest assistance to us, and saw us out of a difficulty which was of deep concern to the Committee.

In many ways the Gladstone Harbour Board helped to make our burden lighter financially and otherwise.

The boring gear was loaded on to the "Cape Leeuwin" at Gladstone on Saturday, 8th May, 1937, and, after certain essential lighthouse services had been fulfilled, was unloaded at Heron Island on Tuesday, 11th May, 1937, by means of a cattle punt obtained in Gladstone and transported with the rest of the gear. Something like 23 tons of gear were unloaded in four punt loads. The first three loads composed of casing, rods, bits, &c., were jettisoned temporarily into the shallow water near the bore-site, so as to save time while the tide was in, and permit of loading the last load, which consisted of the engine and derrick, each item of the order of 3 tons.

Much consideration had been given beforehand to the selection of suitable tidal conditions for landing the gear and the actual day of landing gave us spring-tide conditions with high water about 9 a.m.

Although unloading commenced early and a motor boat came out over the reef as soon as there was enough water to tow the first punt load, we were able only with the greatest difficulty to get the punt off after getting rid of its third load.

It was necessary, therefore, to leave the punt loaded with the engine and derrick outside the reef until the next flood tide whereon it was towed inside and was safer, for even if it now sank the gear could be recovered. By great good fortune we had perfect conditions as far as wind and tide were concerned and all one's previous calculations remained good!

By the use of a hand-winch, a set of tram-rails, much ingenuity and energy, the gear was drawn up above high water level and by Saturday evening, 15th May, everything had been completed to enable boring operations to commence on the Monday morning. These commenced with an official opening on Monday morning, 17th May, in the presence of some seventy people, the great majority of whom were secondary school girls from Victoria who were spending a week at Heron Island. Addresses were given by myself as Chairman of the Committee, by Mr. J. B. Henderson, a member of the Committee, and Mr. J. Binney, the Engineer for Boring, Mines Department, Victoria, who had supervised the preparation and erection of the plant.

Following upon these addresses Mrs. J. B. Henderson started the operations.

The Committee was very fortunate in arranging with one of its members, Mr. J. B. Henderson, O.B.E., F.I.C., F.C.S., who had lately retired from the office of Queensland Government Analyst, to act at the bore-site as its scientific representative. While the general supervision of the boring plant was carried out by Mr. J. Binney through the foreman, Mr. Tom Hughes, the wishes of the Committee were communicated through Mr. Henderson, who also supervised the collection and transportation to Brisbane of the bore samples.

The most harmonious relations were maintained throughout the whole period of operations and the Committee is more than satisfied with the manner of sampling and recording of the material encountered by the boring operations, also with the manner in which the latter were carried out.

The log of the bore as prepared by a draughtsman on the basis of information supplied by Mr. Henderson is very complete, and essentially the record is a repetition of that established ten years ago by the boring at Michaelmas Cay some 700 miles further to the north-west along the "reef." (Plate XV.)

It is difficult to believe it is merely a coincidence that in each case loosely coherent coralline material extends to a depth of approximately 450 feet below the surface level, there to be succeeded by non-coralline material in the nature of loosely coherent quartz sand with abundant foraminifera and littoral shell fragments such as one finds on the existing beaches in these latitudes to-day.

Six hundred feet and 732 feet were the respective depths of the bores at Michaelmas Cay and Heron Island, and once the coralline material was passed through it was not again encountered in either case.

Another coincidence in the results is the absence of dolomitisation of the coralline mass. This has been determined definitely at Michaelmas Cay, and preliminary tests on the Heron Island samples indicate a similar absence.

In the Heron Island bore a series (eight) of siliceous foraminiferal limestone bands were met below the coral and good core samples were obtained. These bands may be quite thin, but four are of the order of 18 inches to 2 feet and the thickest is 78 inches.

In the Michaelmas Cay bore about 10-11 feet in the aggregate of what was believed to be "niggerhead" blocks were passed through in the 437 feet of coralline material, but nothing of the kind was recognised in the Heron Island Bore.

Apart from these two items of difference and the slight difference (13 feet) in thickness of the coralline mass the boring results have been remarkably in line and the value of the borings seems thereby to be much enhanced.

The Honorary Secretary of the Committee as on the previous boring occasion invited leading coral reef authorities and others to submit in writing their forecasts as to the results of the borings, especially as to the thickness of the coral, the nature of the underlying mass, and the depth of the old platform. These forecasts differed widely and, unfortunately, we were compelled with great reluctance to suspend boring operations before we encountered the supposed underlying old rock platform. We do not yet know what lies below these loosely coherent quartz foraminiferal sands with their occasional hard bands of siliceous foraminiferal limestone containing present-day shell fragments.

Before operations commenced and bearing in mind our Michaelmas Cay experience the supervising engineer and foreman felt confident that by starting with 8-inch casing we should be able to reach a depth of appreciably more than 1,000 feet—at least 1,200 feet.

As it turned out even when we were down as far as 510 feet we still thought so, but here we met the first of the really very hard and tough siliceous limestone bands which necessitated a reduction in the size of the casing. At 672 feet another reduction was again forced on us, and as we had been using 4-inch casing below 512 feet we were for all practical purposes finished unless the rock remained hard and casing was no longer required. The rock matrix encountered was compact to hard until 698 feet, and then 23 feet of quite loose sand was met, to be succeeded by 7 feet of rock from 721-728 feet, below which was more loose sand which was penetrated for 4 feet to a total depth of 732 feet.

It was far too risky to bore any deeper without casing, and as even 4-inch casing is rather difficult to work in, the question of any further reduction in size was out of the question.

The 8-inch, 7-inch, and 6-inch casings ended at depths of 31 feet 6 inches, 131 feet, and 340 feet, respectively, simply because those were the lengths we had available for use, but had we obtained greater supplies of the 7 and 6-inch material or even of the latter alone we could of course have pursued our operations to greater depth.

Also had we an under-reamer that would have operated successfully at the 510-516′ 6″ hard band and so let the 5-inch casing through we could have taken this sized casing, of which we had purchased 700 feet, to that depth, and then continued with the 4-inch.

It was not practicable to obtain an under-reamer which would operate satisfactorily because, we understand, of the differences in size of the swell-jointed casings for which the available under-reamers were made and of the flush-jointed casing we were using.

It finally reduced itself very largely to a question of pounds, shillings, and pence. The Committee reviewed carefully the objectives of the boring, the expenditure already incurred, the results already achieved, the results which might be further achieved, and the probable and possible expenditures to get these.

After deliberate consideration of all points and especially because of the difficulty of obtaining a suitable under-reamer we ceased operations at 732 feet without reaching the supposedly underlying old rock platform.

The proposal of putting down another borehole at Heron Island and starting with larger casing was considered, but purely on financial considerations was rejected. Even if the Committee had been strong enough financially to do it, the putting down of another bore on the same area would not be justified as we would repeat 732 feet of available information and a new site somewhat distant should be selected.

To those not familiar with the constitution and financial resources of the Committee it would be well to point out that the work is carried on with monies given voluntarily by individuals, firms, universities, and Governments. We have no definite income, but solicit funds for particular projects in hand. The expenditure incurred for this particular boring operation amounted to £2,190, approximately.

Views have been expressed as to whether we should have bored at all in the southern end because of the gradual tailing off as it were of the great coralline mass as a whole, and the general inference that the "reef" must necessarily be rather poor in these regions.

The best answer to these views is given by a personal visit to the Capricorn Group where the corals are really flourishing to-day.

After Dr. C. M. Yonge had spent nearly a whole year working on the Barrier Reef coral patches, from Low Isles near Cairns northwards to Torres Straits, he visited these southern coral cays, especially Heron Island, and he was entranced and surprised at the luxuriance of the coral growths which flourish in these latitudes. He writes*—

> "That reefs can flourish here at all—and, as we shall see, the coral, though it grows more slowly, is just as luxuriant as that of the more northern reefs—is the result of a warm current which begins in the equatorial regions and flows down outside the Barrier."

He noted particularly the clarity of the water, the white sandy bottoms, and the complete absence of mud which is discharged by the coastal streams and deposited in the lagoon areas where the strip between the Outer Barrier and the coastline is narrow in the northern portions.

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* C. M. Yonge: "A Year on the Great Barrier Reef," p. 202.

He wrote further*—

> "Although a detailed analysis of the coral population was quite impossible in the short time, the impression gained was that there were rather fewer kinds of coral there than in the more northern regions, but that the growth of those that flourished there was no whit less luxuriant."

Dr. Yonge was impressed in just the same way as is everyone else with knowledge of the northern reefs who sees the Capricorn Coral Cays for the first time.

Unquestionably there can be no valid objection to the location of the bore-site here on the basis of luxuriance of coral growth.

Mr. M. Spender† recently ventured the opinion that before this boring was undertaken, preliminary prospecting either with numerous shallow bores or with modern geophysical methods should be carried out. In support of this view he indicates that Dr. Bullard, of Cambridge, and Dr. Brockamp, of Potsdam, agreed that both pendulum gravity surveys and seismic soundings could be used in the Barrier Reef area.

The Committee has for at least four years given very close attention to the question of invoking the aid of geophysical methods, especially for determining two things—(1) the thickness of the coralline matrix, and (2) the depth of the old rock platform.

We have been hopeful of finding a use for both pendulum gravity surveys and seismic soundings, but with the evidence already gained by the Michaelmas Cay boring we quite definitely preferred to defer the application of geophysical methods until we knew more as a result of the very positive old-fashioned boring methods.

We had not been able to learn of any gravity method that was at all reasonable in its cost of operation in these regions, and, moreover, our problem was to see any great value in a gravity survey if we have, as at Michaelmas Cay, about 450 feet of fragmental coralline material resting on some unknown thickness of loosely coherent siliceous sand containing abundant foraminifera and calcareous shell fragments.

The very important thing we wish to know is the thickness of the coral matrix and its physical condition.

The disparity between the densities of the coralline material and that below it did not appear to be sufficiently great bearing in mind the upper thickness to enter into expensive operations.

With regard to seismic tests we were able to establish close contact with Mr. M. Modriniak, of the Department of Scientific and Industrial Research in New Zealand, and at quite a moderate expense we could have applied both the refraction and reflection methods to our area,

* C. M. Yonge: "A Year on the Great Barrier Reef," p. 207.

† Geogr. Jour. No. 2, 1937, p. 142.

especially with a view to determining the depth of the old rock platform.

We considered, however, that we would be well advised to have certain positive information as to the depth of the platform before applying seismic methods, and if these in their results corresponded with the boring results we would feel confidence in using the seismic methods in many places over the Barrier Reef area in order to determine not only the depth of the old rock platform, but also the general character of its surface.

As has already been indicated, the boring encountered several very compact, siliceous limestone bands, and while, no doubt, account could be taken of these and these effects either discarded or obviated (especially when you know they are there) one feels that the postponement of the seismic tests was not altogether without wisdom.

The recent application of seismic methods off the coast of Massachusetts, U.S.A., by Ewing Miller and others* has been of great interest in this connection, because it has been shown that both the refraction and reflection methods may be used to advantage in determining the thickness of unconsolidated and semi-consolidated material near the edge of a continental shelf, and the depth of the old rock platform at great depth may be ascertained.

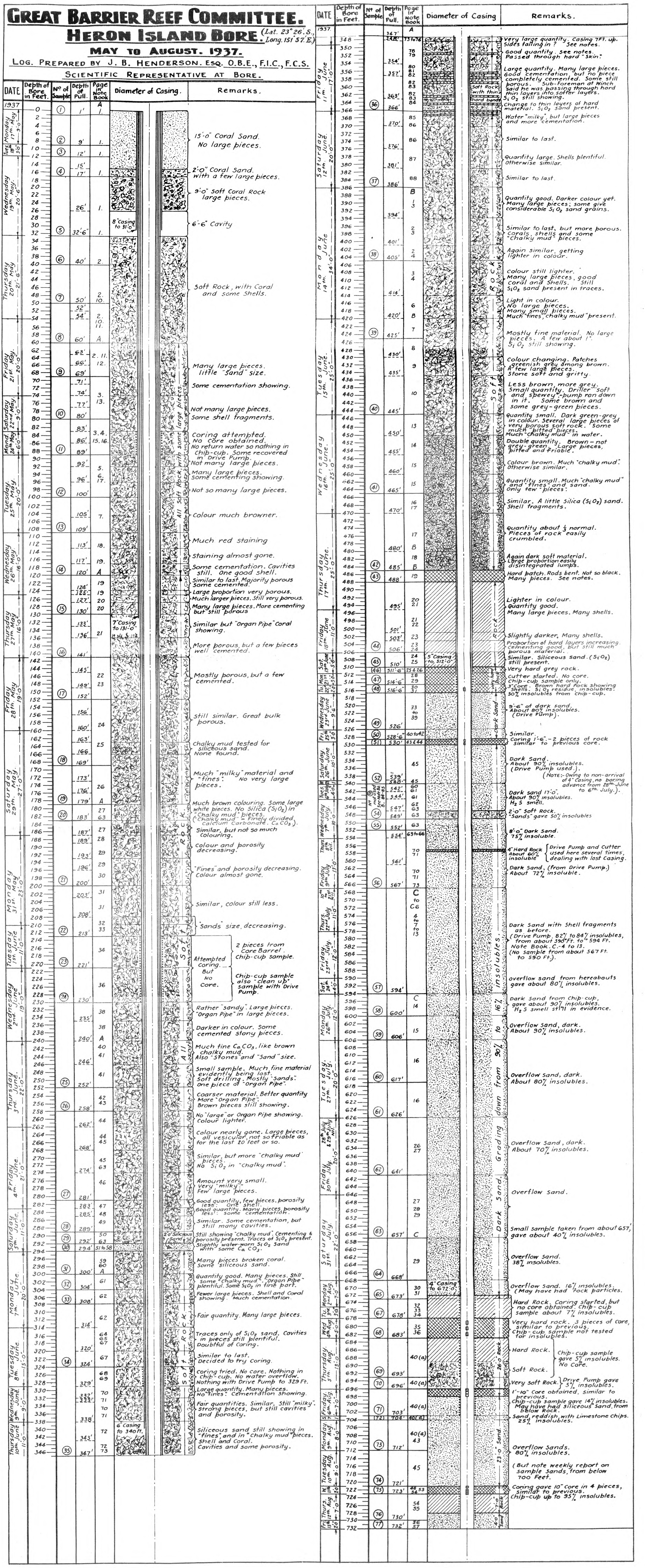
The more important results came from the refraction measurements, and in the present state of development, the method is not applicable in water deeper than 100 fathoms.

There is little doubt that in the near future we will be able to apply seismic methods to great advantage in the Barrier Reef area, more especially if we have really positive evidence from boring methods in one or two key positions.

Steps are being taken to have very complete and careful examination made of the samples collected by Mr. Henderson, and at a later date the results of these investigations will be published; also it is hoped that the Committee will be able to distribute representative samples of the borings over a wide field of institutions.

* Bul. Geol. Soc. Amer. Vol. 48, No. 6, June 1st., 1937, p. 753.

DAVID WHYTE, Government Printer, Brisbane.



Great Barrier Reef Committee.
Heron Island Bore. (Lat. 23° 26' S., Long. 151° 57' E.)
May to August. 1937.
Log. Prepared by J. B. Henderson. Esq. O.B.E., F.I.C., F.C.S.
Scientific Representative at Bore.
Date
Depth of Bore in Feet.
No of Sample
Depth of Pull.
Page in Note Book
Diameter of Casing.
Remarks.
15'-0" Coral Sand. No large pieces.
2'-0" Coral Sand. with a few large pieces.
9'-0" Soft Coral Rock large pieces.
8" Casing to 31'-0"
6'-6" Cavity
Soft Rock, with Coral and some Shells.
Many large pieces. little "Sand" size.
Some cementation showing.
Not many large pieces. Some shell fragments.
Coring attempted. No core obtained. No return water so nothing in Chip-cup. Some recovered in Drive Pump.
Not many large pieces.
Many large pieces. Some cementing showing.
Not so many large pieces.
Colour much browner.
Much red staining
Staining almost gone.
Some cementation. Cavities still. One good shell.
Similar to last. Majority porous. Some cemented.
Large proportion very porous.
Much larger pieces. Still very porous.
Many large pieces. More cementing but still porous
7" Casing to 131'-0"
Similar but "Organ Pipe" Coral showing.
More porous, but a few pieces well cemented.
Mostly porous, but a few cemented.
Still similar. Great bulk porous.
Chalky mud tested for siliceous sand. None found.
Much "milky" material and "fines". No very large pieces.
Much brown colouring. Some large white pieces. No Silica (SiO_2) in "Chalky mud" pieces. ("Chalky mud" = Finely divided Calcium Carbonate. $CaCO_3$).
Similar, but not so much colouring.
Colour and porosity decreasing.
"Fines" and porosity decreasing. Colour almost gone.
Similar, colour still less.
"Sands" size, decreasing.
Attempted Coring. But No Core.
2 pieces from Core Barrel - Chip-cup Sample.
Chip-cup sample also "clean up" sample with Drive Pump.
Rather "sandy". Large pieces. "Organ Pipe" in large pieces.
Darker in colour. Some cemented stony pieces.
Much fine $CaCO_3$, like brown chalky mud. Also "Stones" and "Sand" size.
Small sample. Much fine material evidently being lost. On drilling. Mostly "Sands". One piece of "Organ Pipe".
Coarser material. Better quantity More "Organ Pipe". Brown pieces still showing.
No "large" or Organ Pipe showing. Colour lighter.
Colour nearly gone. Large pieces, all vesicular, not so friable as for the last 20 feet or so.
Similar, but more "chalky mud" pieces. No SiO_2 in "Chalky mud".
Amount very small. Very "milky". Few large pieces.
Good quantity, few pieces, porosity less. One shell.
Good quantity "chalky mud", "Organ Pipe" less. Some cementation.
Similar. Some cementation, but still many cavities.
Still showing "chalky mud". Cementing & porosity present. Traces of SiO_2 present. Slightly water-worn SiO_2 sand with some $CaCO_3$.
Many pieces broken coral. Some siliceous sand.
Quantity good. Many pieces. Still some "chalky mud". "Organ Pipe" plentiful. Some SiO_2 in fine part.
Fewer large pieces. Shell and Coral showing. Much cementation.
Fair quantity. Many large pieces.
Traces only of SiO_2 sand. Cavities in pieces still plentiful. Doubtful of Coring.
Similar to last. Decided to try coring.
Coring tried. No core. Nothing in chip-cup. No water overflow. Nothing with Drive Pump to 329 Ft.
Large quantity. Many pieces. No "fines". Cementation showing.
Fair quantities. Similar. Still "milky". Strong pieces, but still cavities and porosity.
6" Casing to 340 Ft.
Siliceous sand still showing in "fines" and in "chalky mud" pieces. Shell and Coral. Cavities and some porosity.
All Soft Rock with some large pieces
Soft Rock
Very large quantity. Casing 7 Ft. up. Sides falling in? See notes.
Good quantity. See notes. Passed through hard "Skin".
Large quantity. Many large pieces. Good cementation but no piece completely cemented. Some still porous. Sub-Foreman at Winch said he was passing through hard thin layers into softer layers. SiO_2 still showing.
Soft Rock with thin hard bands
Change to thin layers of hard material. SiO_2 sand present.
Water "milky", but large pieces and more cementation.
Similar to last.
Quantity large. Shells plentiful. Otherwise similar.
Similar to last.
Quantity good. Darker colour yet. Many large pieces; some give considerable SiO_2 sand grains.
Similar to last, but more porous. Corals, shells and some "chalky mud" pieces.
Again similar, getting lighter in colour.
Colour still lighter. Many large pieces, good coral and shells. Still SiO_2 sand present in traces.
Light in colour. No large pieces. Many small pieces. Much "fines", chalky mud" present.
Mostly fine material. No large pieces. A few about 1". SiO_2 still showing.
Colour changing. Patches greenish grey among brown. A few large pieces. Stone soft and gritty.
Less brown, more grey. Small quantity. Driller "Soft and spewey" - pump ran down in it. Some brown and some grey-green pieces.
Quantity small. Dark green-grey in colour. Several large pieces of very porous soft rock. Some much "pitted" pieces. Much "chalky mud" in water.
Double quantity. Brown - not grey-green. Large pieces, pitted and friable.
Colour brown. Much "chalky mud". Otherwise similar.
Quantity small. Much "chalky mud" and "fines" and sand. Only few "pieces".
Similar. A little Silica (SiO_2) sand. Shell fragments.
Quantity about ½ normal. Pieces of rock easily crumbled.
Again dark soft material. Large proportion easily disintegrated lumps.
Hard batch. Rods bent. Not so black. Many pieces. See notes.
Soft Rock
Lighter in colour. Quantity good. Many large pieces. Many shells.
Slightly darker. Many shells.
Proportion of hard layers increasing. Cementing good, but still much porous material.
Similar. Siliceous sand. (SiO_2) still present.
5" Casing to 512'-0"
Very hard grey rock.
Cutter started. No core. Chip-cup sample only.
3'-0" Brown hard rock showing shells. SiO_2 residue, insolubles. 30% insolubles from chip-cup.
5'-6" of dark sand. About 80% insolubles. (Drive Pump).
Similar.
Coring 1'-6". - 2 pieces of rock similar to previous core.
Dark Sand. About 90% insolubles. (Drive Pump used.)
(Note:- Owing to non-arrival of 4" casing, no boring advance from 28th June to 6th July.)
Dark sand 17'-0". About 90% insolubles. H_2S smell.
2'-0" Soft Rock.
"Sands" gave 50% insolubles
8'-0" Dark Sand. 75% insoluble.
4' Hard Rock About 60% insoluble
Drive Pump and Cutter used here several times, dealing with lost Casing.
Dark Sand. (from Drive Pump.) About 72% insoluble.
Dark Sand with Shell fragments as before. (Drive Pump. 82% to 84% insolubles, from about 590 Ft. to 594 Ft. Note Book. C-4 to 13. (No sample from about 567 Ft. to 590 Ft.)
Overflow sand from hereabouts gave about 80% insolubles.
Dark Sand from Chip-cup, gave about 90% insolubles. H_2S smell still in evidence.
Overflow Sand, dark. About 90% insolubles.
Overflow Sand, dark. About 80% insolubles.
Overflow Sand, dark. About 70% insolubles.
Overflow sand.
Small sample taken from about 657', gave about 40% insolubles.
Overflow Sand. 38% insolubles.
Dark Sand. Grading down from 90% to 16% insolubles.
4" Casing to 673'-0"
Overflow Sand. 16% insolubles. (May have had rock particles.
Hard Rock. Coring started, but no core obtained. Chip-cup sample about 7% insolubles.
Very hard rock. 3 pieces of core, similar to previous. Chip-cup sample not tested for insolubles.
Hard Rock.
Soft Rock.
Chip-cup sample gave 5% insolubles. No Core.
Very Soft Rock.
Drive Pump gave 5% insolubles.
1'-10" Core obtained. Similar to previous.
Chip-cup sample gave 14% insolubles. May have had siliceous Sand, from below Rock.
Sand, reddish with Limestone Chips. 25% insolubles.
Overflow Sands. 80% insolubles.
(But note weekly report on sample Sands, from below 700 Feet.
Coring gave 10" core in 4 pieces, similar to previous. Chip-cup up to 95% insolubles.
23'-0" Sand.